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PROPOSED SPECIFICATIONS FOR INTERNATIONAL INTEROPERABILITY ON REPAIRED BOMB DAMAGED RUNWAYS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This paper suggests definitions for data, data formats, and National responsibilities for development of war emergency airfield pavement repair specifications. An airfield manager would use these specifications to make repairs after an enemy attack. Minimum Operating Strip size, repair quality, repair spacing, and other parameters are specified. If the repair specifications for a specific aircraft can not be met, then discrepancies can be identified and the aircraft operator could assess the additional risk. Exchange of these specifications

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20. ABSTRACT (CONTINUED)

between the nation operating an aircraft and the nation managing an airfield would enhance NATO interoperability.

PREFACE

This report was prepared by the Rapid Runway Repair Branch, Engineering and Services Laboratory, HQ Air Force Engineering and Services Center at Tyndall Air Force Base, Florida 32403, under Job Order Number 21042B43 during the period June 1980 through January 1981.

The purpose of this report is to present ideas for suggested specifications that describe the requirements for repair of an airfield's pavement after an attack. These suggestions are not expected to be the final solution but are presented here to initiate technical discussion.

This report has been reviewed by the HQ AFESC Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public including foreign nationals.

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SECTION I

INTRODUCTION

1.0 The present scenario for a conventional war in a European environment depicts a fast moving, high intensity engagement. Extensive airfield pavement damage is anticipated and rapid, high rates of launch and recovery of aircraft are required. Some of the launched aircraft may be recovered at an alternate base. Personnel at this alternate base may or may not be familiar with that particular aircraft. When the aircraft is operated by one nation and the alternate airfield managed by another nation, the problem of interoperability on different types of bomb crater repairs arises.

2.0 NATO Standardization Agreement (STANAG) 2929 (ADR), Airfield Damage Repair (Ref 9) defines the need to repair an airfield after an attack. This report suggests definitions for data, data formats, and national responsibilities for development of war emergency airfield pavement repair specifications. Throughout this report the term airfield manager is used to mean the Nation or National agency responsible for operating a specific airfield or group of airfields. The term aircraft operator is used to mean the Nation or National agency responsible for operating a particular aircraft, although that aircraft may be manufactured by some other nation.

3.0 An airfield manager would use these specifications for one or more aircraft to select a Minimum Operating Strip (MOS) and to repair the airfield's pavement after an enemy attack as shown in Figure 1. MOS size, repair quality, repair spacing, and other parameters must be specified. If repair specifications for a specific aircraft are impracticable, then discrepancies can be identified and the aircraft operator can determine if the risk is acceptable, or decide to evacuate one or more types of aircraft using an Evacuation Strip. Exchange of these specifications between the nation operating an aircraft and the nation managing an airfield would enhance NATO interoperability.

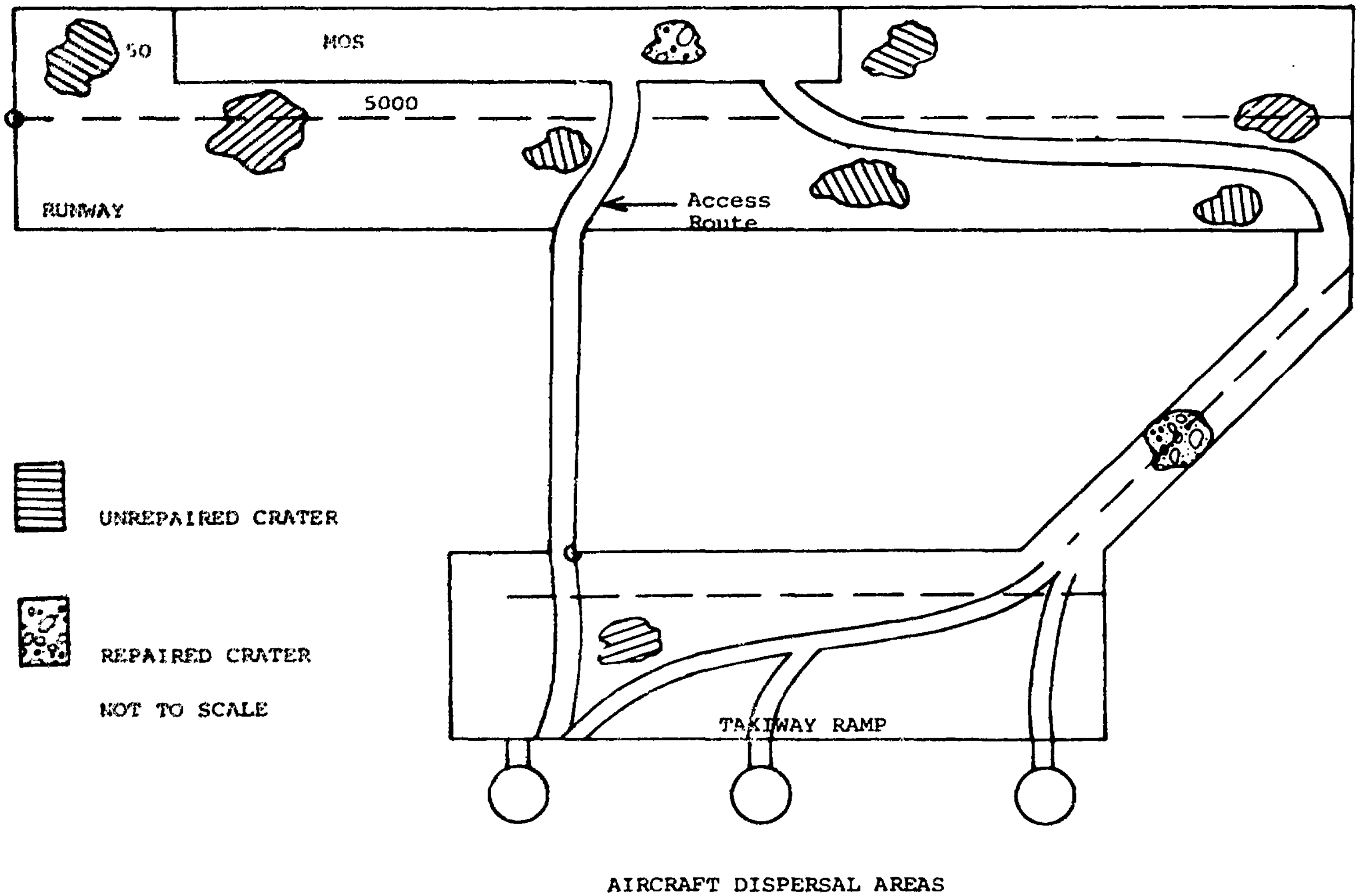


Figure 1. Typical MOS

SECTION II

GENERAL DISCUSSION

1.0 Several NATO countries have been conducting independent tests to predict the effect of expedient pavement repairs on the structural loads induced in an aircraft operating over these repairs. Testing suggests wide variations in the tolerance of specific types of aircraft to surface roughness. Based upon test results to date it appears that it will be difficult (if not impossible) to extrapolate the effects of surface roughness on one specific type of aircraft, such as a F-4E Phantom to a second type of aircraft such as a F-15 Eagle. It will even be difficult for field personnel to extrapolate the effects of surface roughness on a F-4E to a F-4C.

2.0 The purpose of the report is to attempt to "standardize" and minimize the data that will be required to specify repair requirements for a bomb damaged runway for a specific type of aircraft. Since an airfield must be compatible with many different types of aircraft, it is necessary that this data can be combined or merged. Each airfield can then project the optimum repairs to accommodate the anticipated mix of aircraft that will use the airfield, although these aircraft may be designed, manufactured and operated by different nations.

3.0 Preparation of this report required adoption of the assumptions which are listed below.

3.1 War Emergency Only. These airfield repair specifications will be used in time of war for expedient repairs and will not be used under peacetime conditions or for permanent repairs.

3.2 Time to Repair. After an enemy attack has occurred, the estimated "time to repair" will be the primary factor used to trade off the selection of various MOS that could be repaired. Lower priority aircraft mission requirements may have to be sacrificed to do the high priority mission tasks as expeditiously as possible.

3.3 Quality of Repair. Perfect repairs (smoothness) require more time than imperfect repairs. Significant amounts of time and resources may be saved by making poorer quality repairs.

3.4 Aborts. In the European conventional war scenario the need to launch and recover aircraft is so high that the loss of aborting aircraft is an acceptable risk. This assumption is necessary to place reasonable limits on MOS size and repair quality.

4.0 The determination of acceptable repair specifications is affected by aircraft design, operational techniques, acceptable

risk levels, pilot ability and National objectives. The establishment of these specifications should, therefore, be the responsibility of the nation operating the aircraft. The aircraft operator should include in these requirements his assessment of wartime emergency acceptable risk and specify the "worst case" repair that he can tolerate. Over specification could easily result in the inability of the airfield repair crew to meet the stated repair requirements in a timely manner.

5.0 The nation managing a specific airfield is responsible for reviewing each specific aircraft's specifications and estimating its ability to meet those specifications. It is possible that Merging of specifications for several aircraft to create a "worst case" specification may result in inability of the airfield manager to respond rapidly. Mission priorities therefore may dictate that a specific airfield cannot spend the time or resources necessary to meet repair specifications for a specific type of aircraft or a particular mix of aircraft.

6.0 If an airfield manager determines that repair specifications for a specific type of aircraft cannot be met, the manager must notify the aircraft operator of discrepancies so that the associated risk can be reevaluated, or operational restriction (such as gross weight limitation) imposed if the aircraft must be operated at that field.

7.0 Throughout this report examples of interim repair specifications for an F-4E are presented for a density ratio of 1.0. These interim specifications are extracted from Reference 7. A consolidation of these examples for several density ratios is presented in Appendix A.

8.0 A suggested glossary is included in Appendix B.

SECTION III

MINIMUM OPERATING STRIP REQUIREMENTS

1.0 The requirements for the MOS for each specific aircraft can be different and urgent misson needs at a particular airfield may dictate a necessity to rank repair options by priority. For example, a particular airfield manager may decide (based on time to repair estimates), to first repair a narrow MOS that is only suitable for fighter aircraft, but not adequate for logistic aircraft. Expansion of the MOS for logistic aircraft would normally be accomplished as soon as possible.

2.0 Definition of the following MOS parameters will be required to enable the airfield manager to select and repair a MOS that will be adequate for a specific type of aircraft. Typical data for an F-4E is summarized in Table 1.

2.1 MOS Size. The aircraft operator will specify the minimum MOS width and length that is required for a specific aircraft's anticipated ground roll and 50 foot obstacle clearance under worst case takeoff or landing conditions to include weather, aircraft loading, performance, etc. The aircraft operator is responsible for making the necessary trade-offs between aircraft safety and acceptable operational risks.

2.2 Abort Requirements. Since the anticipated scenario assumes war emergency conditions, it is anticipated that the aircraft operator is willing to accept the loss of aircraft that abort on take-off. The airfield manager will place first priority on achieving the minimum time to repair a MOS and restore the airfield to limited operation. Repairing the airfield to accommodate aborting aircraft will be a secondary priority.

2.3 MOS Marking and Lighting. The airfield manager will mark the MOS with a centerline and threshold as required by reference 9. Portable lighting will be provided for use at night and during low visibility operation. The airfield manager will advise the aircraft operator on the details of actual MOS marking and lighting.

2.4 MOS Direction. Under some repair conditions the MOS may only be suitable for takeoffs and landings in a single direction, (unidirectional MOS). The airfield manager will notify the aircraft operator if the MOS is unidirectional instead of bidirectional.

2.5 Instrument Approaches. The airfield manager will notify the aircraft operator of damage to airfield approach instrumentation and any required deviations from published approaches.

2.6 Barriers/Arrestors: If the airfield manager can provide a barrier or arrestor on the MOS, the manager will advise the aircraft operator of the type and location of the barrier.

3.0 Evacuation Strip. If the airfield is so extensively damaged that it is not practical to repair a MOS, the aircraft operator may request that the airfield manager prepare an Evacuation Strip as discussed in Section IX.

TABLE 1

F-4E MOS REQUIREMENTS

Length	5000 feet (1524 meters)
Width	50 feet (15.24 meters)
Take-off to clear 50 ft obstacle	5700 feet (1767 meters) (3)(4)(6)
Landing over 50 feet obstacle	5300 feet (1615 meters) (3)(4)(5)(6)
Abort Requirements	NONE
MOS Marking	Centerline and Threshold (1) (7)
Lighting	MOS edge. Threshold (1) (7)
MOS Direction	(1)
Instrument Approaches	(1)
Barriers/Arrestors	(1) (2)

Notes:
(1) Airfield manager will advise aircraft operators of specific details as soon as possible after repairs are complete.

(2) Desired but not required.

(3) Worst case density ratio of .9

(4) Dry runway

(5) 38,000 lb Aircraft

(6) Reference 1

(7) Reference 9

SECTION IV

REPAIR QUALITY VERSUS LOCATION

1.0 High quality repairs will require more manpower, materials and repair time than lower quality repairs. A "perfect" repair would require removal of all upheaved concrete and placement of repair material would have to be perfectly flush with the original pavement surface. Considerable time could be saved by leaving some of the upheaved concrete in place, since the removal time would be saved, and the repair area would be smaller, (in some cases by a factor of 2.5). Analyses of effects of the repairs on some aircraft indicate that at very slow (taxi) speeds the aircraft can tolerate relatively rough (low quality) repairs. On the first part of the MOS, while the aircraft is above low taxi speeds but still at moderate speeds where aerodynamic lift is small the repairs will tend to cause high dynamic loads in the aircraft, but as the aircraft builds up lift runway induced aircraft loads will be reduced and additional roughness may be acceptable (Ref 4). The important result of these variations in aircraft tolerance to roughness vs aircraft speed is that the minimum required quality of each pavement repair will vary, depending on location.

2.0 The aircraft operator will define various levels of repair quality, such as "A," "B," or "C" quality, and identify acceptable quality versus location on the MOS as follows.

2.1 MOS Repair Quality. The aircraft operator will specify repair quality versus repair location on the MOS for both unidirectional and bidirectional runways, (Figure 2). This specification could include the effects of density ratio or be a combined "worst case" specification at the option of the aircraft operator.

2.2 MOS Repair Spacing. Since runway repairs will have a reinforcing or cancellation effect, it will also be necessary to specify acceptable repair spacing. This will be provided on a plot that shows location of a repair on the MOS (from start of the MOS) versus the minimum distance to the next repair (Figure 3).

2.3 Touchdown Zone. The aircraft operator will specify any special requirements for the touchdown zone. As an example some aircraft may require perfect repairs in the touchdown zone, which would greatly restrict flexibility in the selection of an MOS.

2.4 Thrust Effects. Since jet engine blast can cause damage to temporary repairs the aircraft operator will identify air velocity and temperature effect due to aircraft prop and jet blast, to include the effects of reverse thrust. The operators should minimize these effects on taxiway repairs through operational restrictions if necessary (Figure 4).

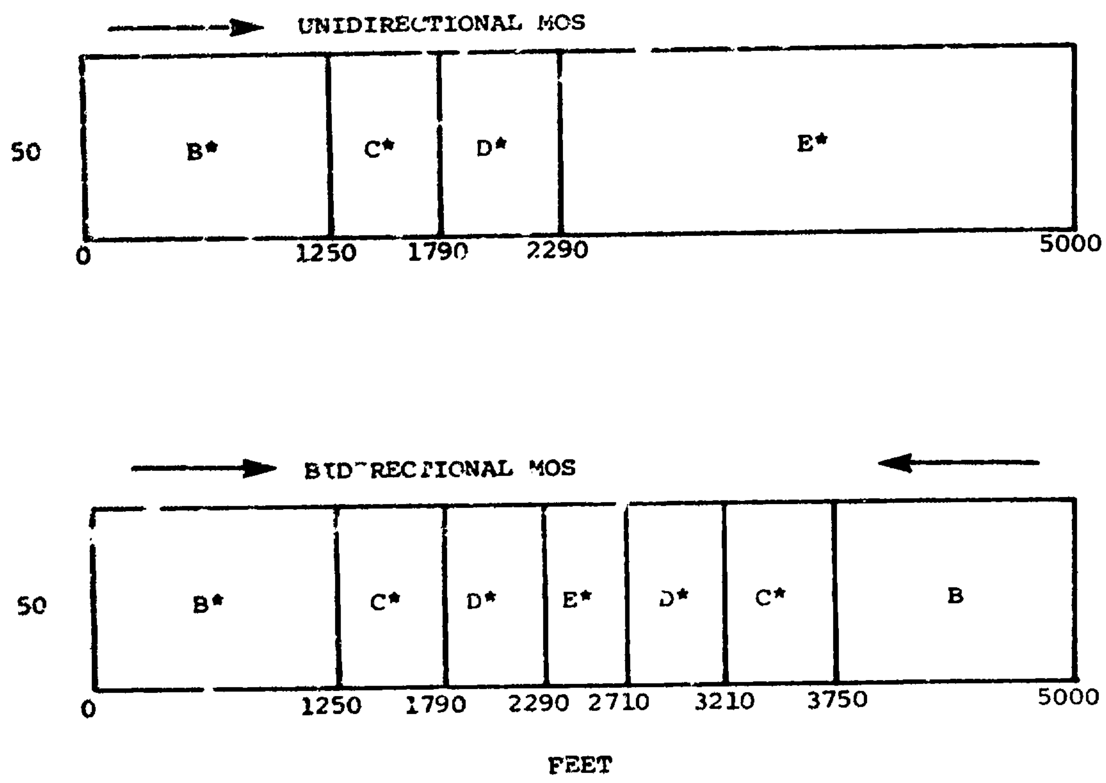


Figure 2. F-4E MOS Repair Quality vs Locations

NOTES: 1. * or better

2. Density Ratio=1.0

3. Repair Quality is defined in Section V

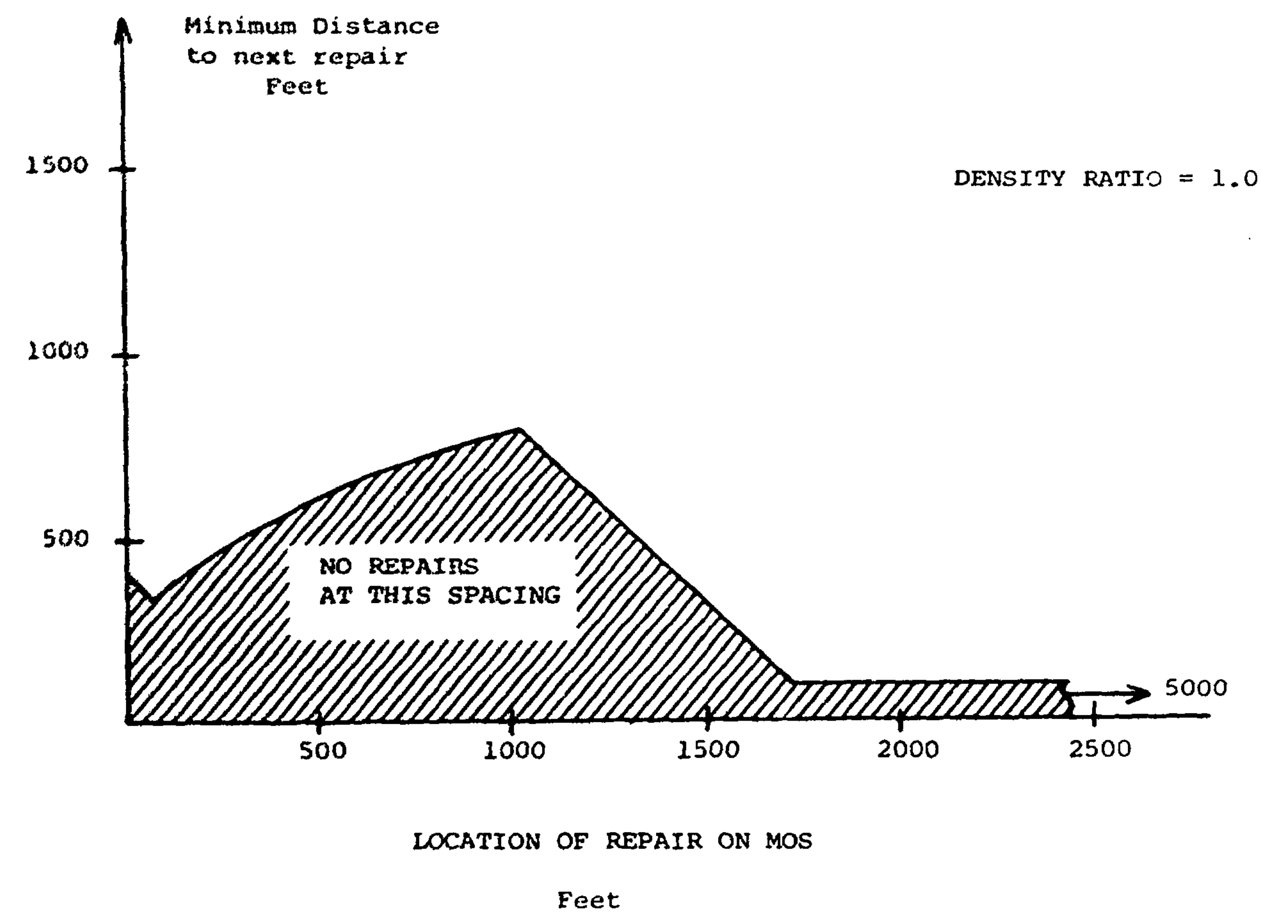
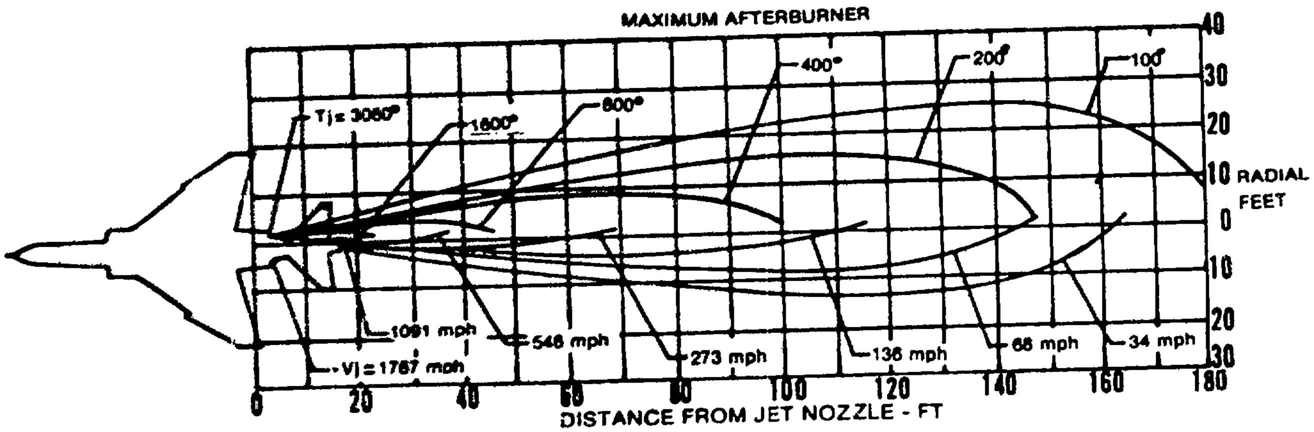


Figure 3. F-4E MOS Spacing



LEGEND	NOTES
— TEMPERATURE T_j TEMPERATURE AT NOZZLE EXIT - - - DISPERSION LIMIT TEMPERATURE/16 — VELOCITY - MPH V_j VELOCITY AT NOZZLE EXIT - - - DISPERSION LIMIT VELOCITY	1. ALL RATINGS GIVEN ARE FOR A STATIC AIRCRAFT AT SEAL LEVEL ON A STANDARD DAY. 2. FOR CLARITY, ONLY ONE ENGINE JET WAKE IS SHOWN. 3. EXTRACTED FROM TO IF-4E-I

Figure 4. F-4E Thrust Effects

SECTION V

INDIVIDUAL CRATER REPAIR SPECIFICATIONS

1.0 Individual craters will be repaired to the qualities discussed in Section IV where a specific repair's quality is a function of its particular location on the MOS and taxiway access routes. In the specification an individual crater repair is considered to be a single crater, overlapping craters, or craters so close together that the repair procedure results in removal of the pavement between the repair.

2.0 The aircraft operator will quantify the following parameters to define quality of repair for each aircraft. This should be done so as to insure that operation on any repair that falls within these specifications will be an acceptable operational risk. The aircraft operator will define repair catagories of increasing quality. This should be done so that a given quality of repair is an acceptable substitute for repairs of lower quality. The airfield manager will be responsible for insuring that the repair quality meets or exceeds these specifications. All repair quality measurements will be made at least along the crater's center and halfway between the center and the crater edge on each side. If a portion of the repaired area falls outside the MOS the quality measurement shall be performed on three equally spaced lines within the MOS. These three lines should be parallel with the MOS's centerline (Figure 5).

2.1 Peak Upheaval. The peak upheaval is the repair peak highest above a line between the undamaged pavement on each side of the repair. The measurement of the upheaval in the field is performed using upheaval markers as shown in Figure 6. These markers permit a string to be stretched taut at certain heights above the pavement surfaces. These heights correspond with the maximum upheaval allowed for each repair quality as defined by the aircraft operator (Table 2). The upheaval marker posts should be located on opposite sides of each crater, outside the limits of pavement upheaval. A string should be stretched between the posts at equal heights above the pavement, corresponding to the allowable maximum upheaval for the applicable repair category. The entire crater repair must lie beneath the string to meet the maximum upheaval criteria. One of the current repair techniques uses an aluminum mat on top of select fill in the crater. The upheaval, as specified in Table 2, must include the thickness of this repair mat.

2.2 Percent Change in Slope. This parameter establishes the maximum rate of change of the repair height relative to the original pavement surface, and is applicable to both the upheaved pavement and the repair surface. For example, if the damaged pavement is heaved up 1.5 inches in 5 feet, then this represents

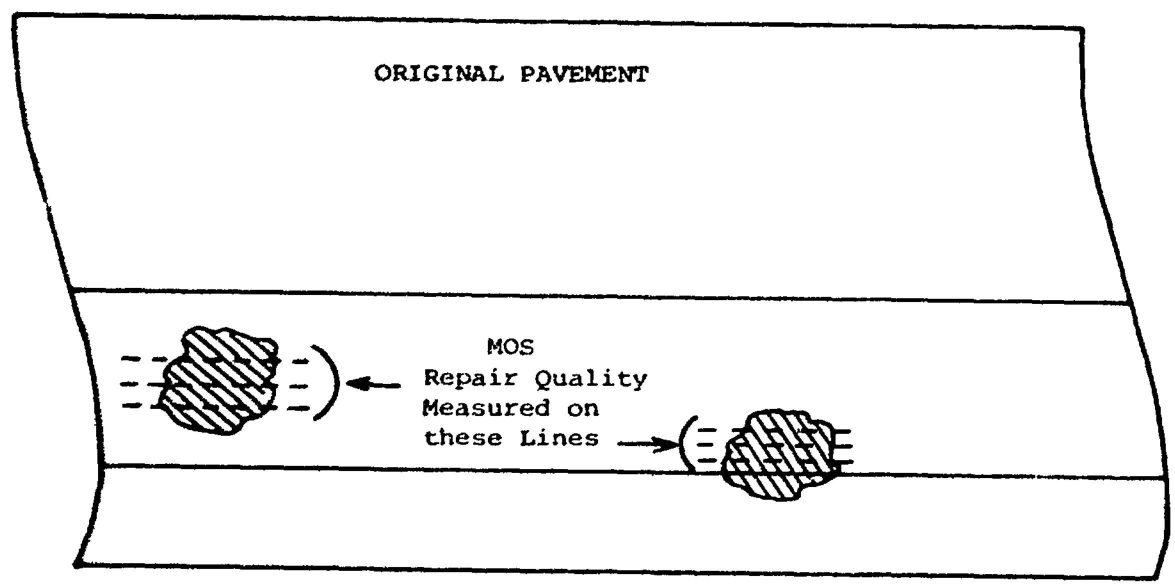


Figure 5. Repair Quality Measurements

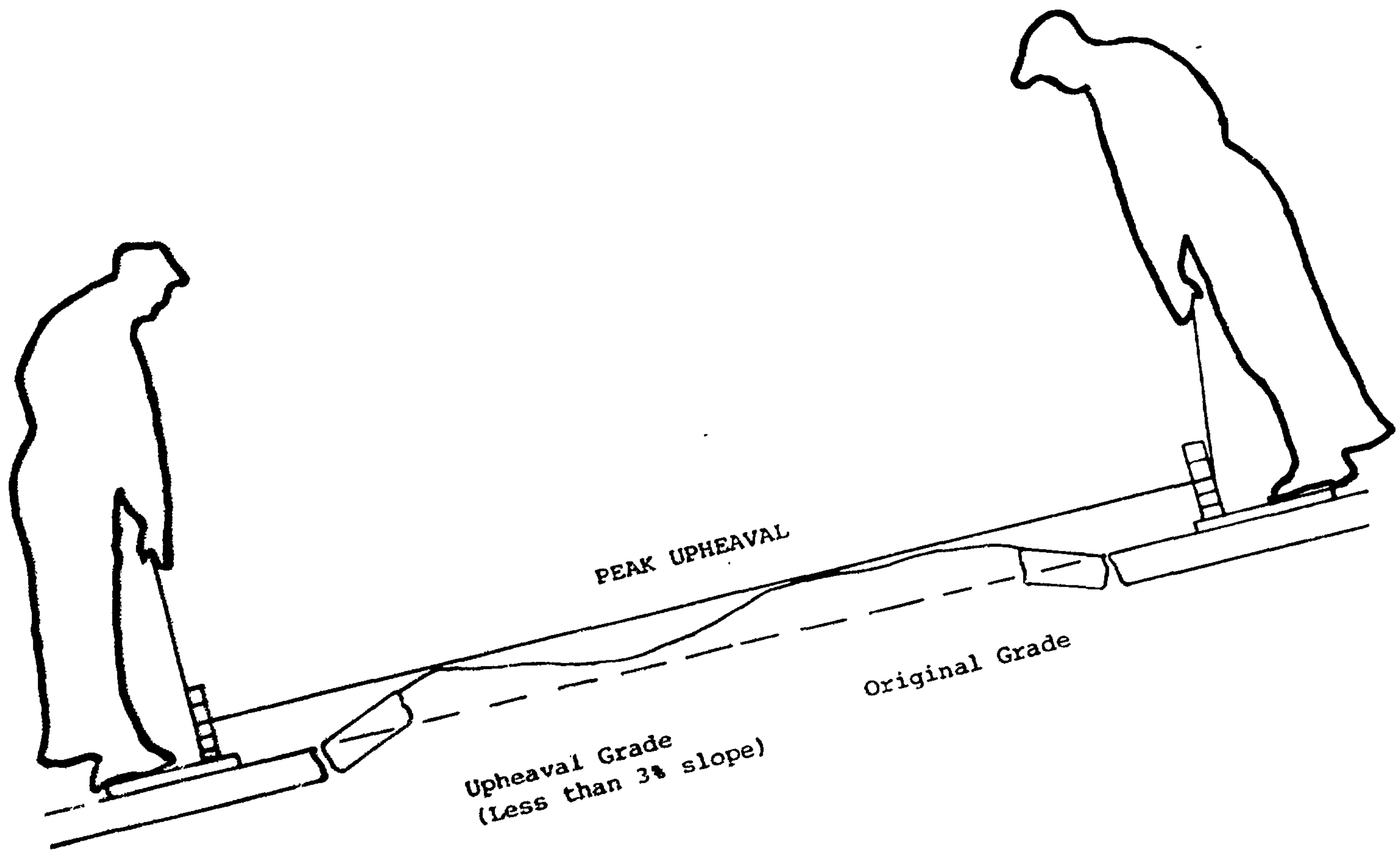


Figure 6. Peak Upheaval Measurement

a [1.5/(5 x 12) = 0.025] 2.5 percent change in slope from the adjacent undamaged pavement. Typically, change in slope would be measured with a template as shown in Figure 7.

TABLE 2

F-4E REPAIR QUALITY CATEGORIES

	A	B	C	D	E
Maximum Upheaval, inches (cm)	1.5 (4)	3.0 (6)	3.0 (6)	3.0 (8)	4.5 (11)
Sag (See Table 3)					
Maximum Length of Crater, feet (meter)	N/A	N/A	70 (20)	70 (20)	N/A
Maximum Change in Slope (percent)	5	5	5	5	5
Special Requirements	(None)	2	2,3	1,3	1,4

Special Requirements

1. Any spacing except that if repairs are closer than 100 feet "D" and "E" repairs must be upgraded, "D" to "A" and "E" to "C" repairs.

2. Must meet spacing criteria, or upgrade to "A" category.

3. Maximum length of a single "C" or "D" repair is 70 feet. If a single repair exceeds 70 feet upgrade to a "B" repair.

4. For landing aircraft E repairs must be 750 feet apart or upgrade to "D."

2.3 Sag. Sag is the vertical distance between the low points of a repair and an "imaginary repair surface." The "imaginary repair surface" is established by stretching a string across the repair so that it contacts the pavement just outside the start of the upheaval (Figure 8). Then the vertical distance (sag) from the repair surface to the string can be measured from the string. The parameters peak sag, nominal sag, and maximum span below nominal sag are defined in the following paragraphs. The span width is a factor because relatively short sags will tend to stimulate the aircraft above its response frequencies and hence will not tend to reinforce aircraft dynamic loads (Table 3).

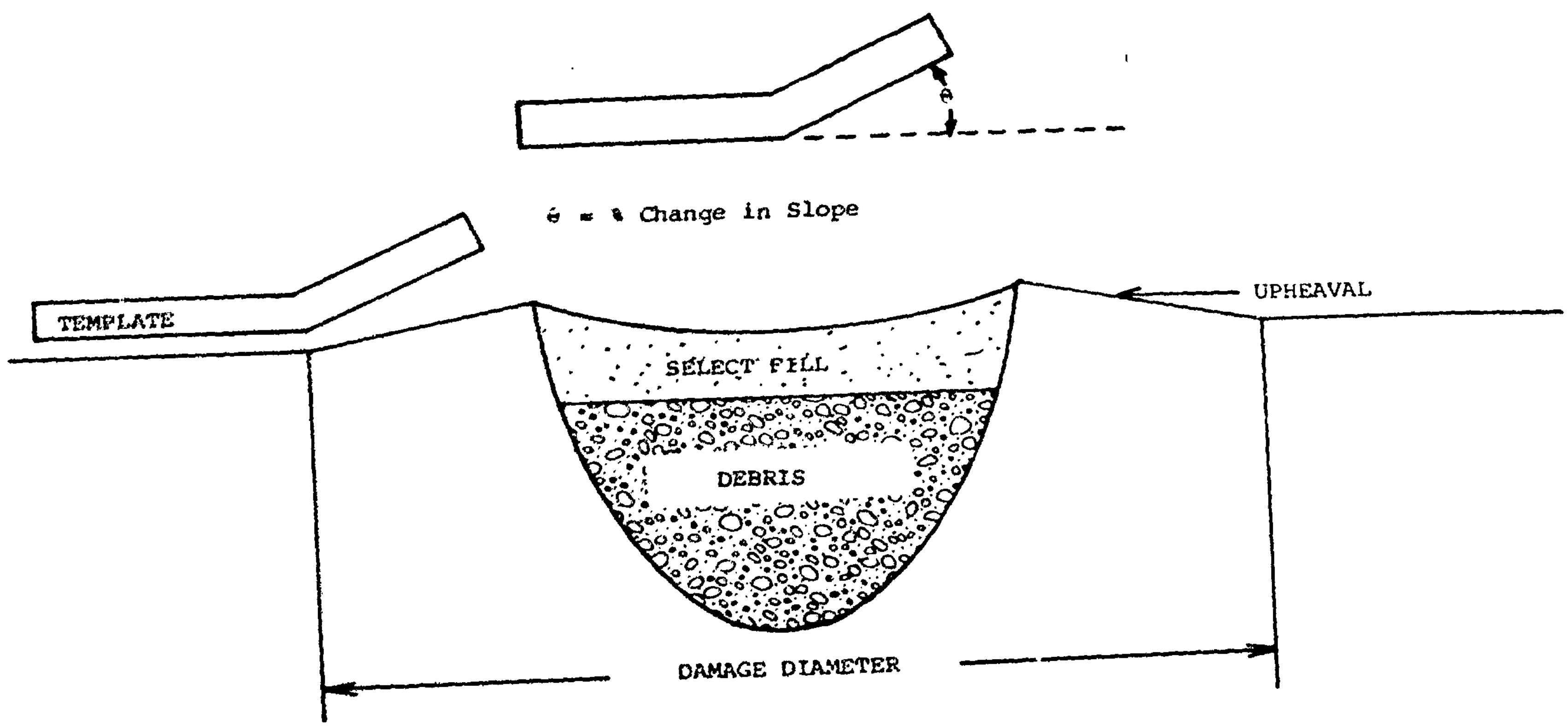


Figure 7. Slope Template

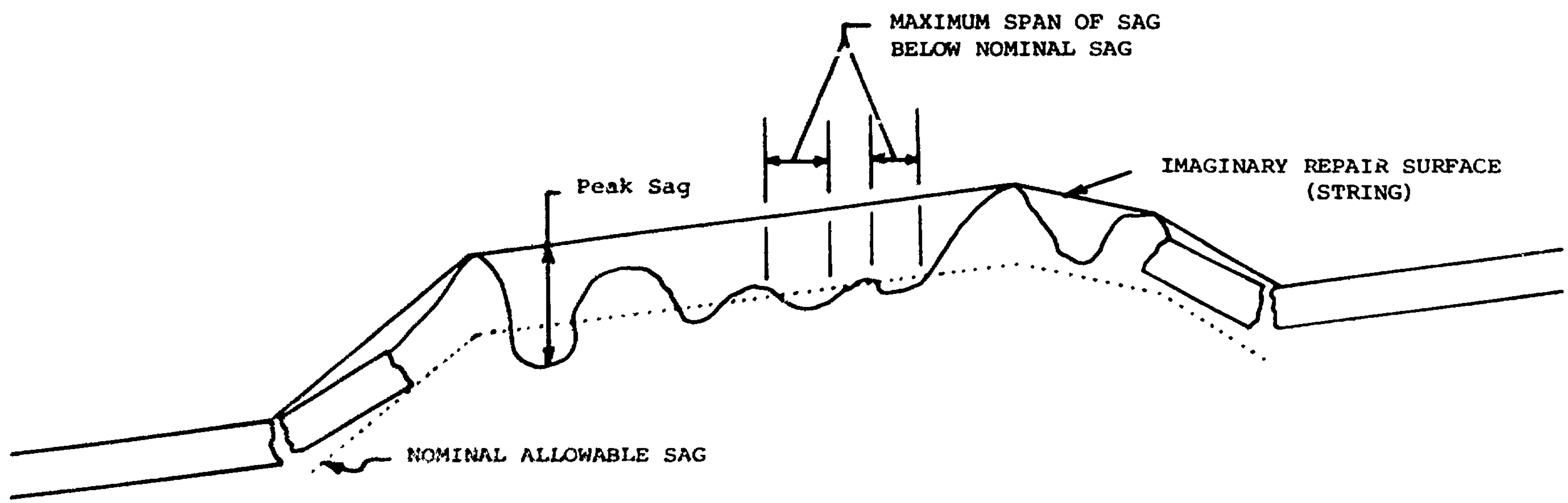


Figure 8. Sag Measurement

TABLE 3

F-4E REPAIR SAG CRITERIA

	REPAIR CATEGORY				
	A	B	C	D	E
Peak Sag Inches (cm)	1.0 (2.5)	1.0 (2.5)	2.5 (6.5)	2.5 (6.5)	4.0 (10.0)
Nominal Allowable Sag Inches (cm)	0.5 (1.5)	0.5 (1.5)	2.0 (5.0)	2.0 (5.0)	3.5 (9.0)
Maximum Span of Sag Below Nominal Sag, feet (m)	5 (1.5)	5 (1.5)	10 (3.0)	10 (3.0)	20 (6.0)

2.3.1 Peak Sag. The peak distance below the string is the peak sag. This peak sag will be specified by the aircraft operator and must be associated with a "maximum span below nominal sag" as discussed below.

2.3.2 Nominal Sag. This sag is the maximum allowable sag that is acceptable without consideration for sag length. There is no associated sag span with the nominal sag.

2.3.3 Maximum Span below Nominal Sag. This parameter defines how wide (how long down the MOS) that sag can exceed the nominal sag towards the peak sag limit. The repair surface must return to a point above the nominal sag at least once in each maximum span. This parameter allows sag to approach the peak allowable sag as long as the effective frequency does not stimulate reinforcement of aircraft dynamic loads.

2.4 Repair Length. Minimum or maximum limits, if any, on repair length shall be specified. Repairs with significant upheaval and sag will probably have a maximum allowable length, and if this length is exceeded then the repair must be upgraded to have less sag or upheaval as is shown for F-4E "C" repairs in Table 2.

2.5 Load Bearing Forces. The aircraft operator will specify the tire pressure, tire footprint, wheel pattern/ spacing, and equivalent single wheel load (Figure 9).

2.6 Braking Force. The aircraft braking forces that must be absorbed by the repair cover will be specified by specific

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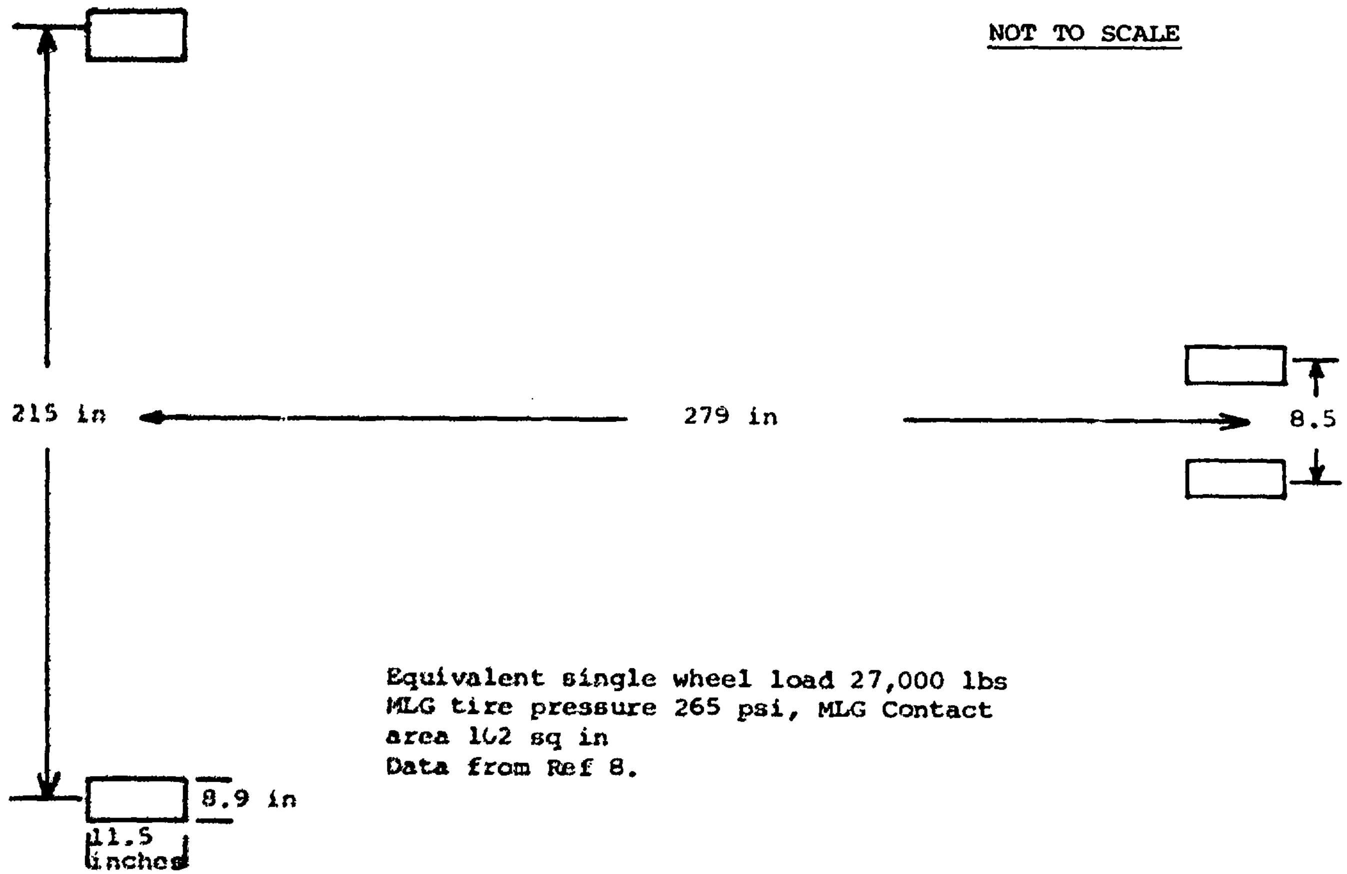

Equivalent single wheel load 27,000 lbs
MLG tire pressure 265 psi, MLG Contact
area 162 sq in
Data from Ref 8.

Figure 9. F-4E Wheel Pattern

wheel location (Figure 9). Variation in braking forces for different locations on the MOS will be specified. The operator will prohibit braking operations on taxiway repairs.

2.7 Assymmetric Repair. At this time, it appears that most aircraft critical loads will not be higher because of assymmetric repairs than those caused by symmetric repairs. Since attempting to make very symmetric repairs may be difficult and time consuming, the aircraft operator should assume that the aircraft may travel assymetrically across the repairs.

3.0 Tolerance. The airfield manager will insure that measurement of repair quality is such that the actual parameters meet or exceed the required specification.

4.0 Quality Control. The airfield manager is responsible for quality control of the repairs and will make periodic inspections for degradation of repair quality.

SECTION VI

SCAB (SPALL) REPAIR REQUIREMENTS

1.0 Strafing, unexploded ordinance, ricochets, explosion debris, etc., may cause extensive scabs (spalls) that could range from slight pavement chipping to almost 5 foot holes that do not penetrate through the pavement (the base course is not exposed).

2.0 This section defines the types of scabs that must be repaired, scab spacing and scab repair parameters.

2.1 Unrepaired Scabs. Some pavement damage will be so slight that repair will not be required. The aircraft operator will define the following parameters to establish the maximum size of unrepaired scabs (Figure 10).

2.1.1 Scab Depth. The peak depth of the scab from a line across the undamaged edges (scabs do not have upheaval since the pavement is not penetrated).

2.1.2 Scab Width. The maximum distance across the scab parallel to the MOS centerline.

2.1.3 Slope of Scab Sides. The slope of a straight line that approximates the side of the scab.

2.1.4 Unrepaired Scab Spacing. Since multiple scabs could reinforce aircraft dynamic loads, it is necessary for the aircraft operator to either specify a scab spacing criteria, or to account for the effects of reinforcement in the maximum unrepaired scab specification.

2.2 Repaired Scabs. Scabs that exceed the specification for unrepaired scabs must be repaired. It is anticipated that a tolerance of ± 3/4-inch from the original surface can be readily met on scab repairs.

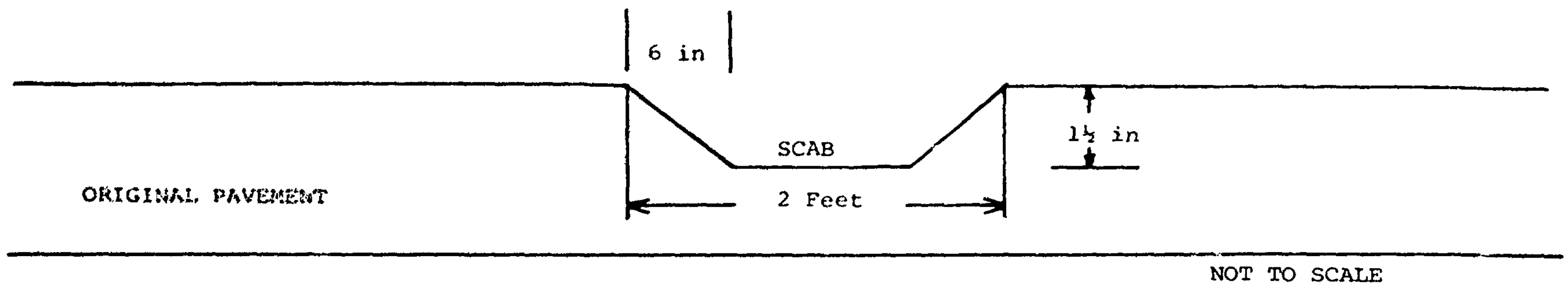

Figure 10. F-4E Unrepaired Scabs

TABLE 4

F-4E UNREPAIRED SCABS

Maximum Depth	1.5 inches (3.8 cm)
Maximum Length Parallel to MOS centerline	2 feet (61 cm)
Maximum Slope of Scab Sides	25%
Spacing Parallel to MOS centerline	No more than 2 scabs per 24 feet (7.3 meters) in a line parallel to the MOS centerline.

Section VII

TAXIWAY REPAIR REQUIREMENTS

1.0 In general taxiway repairs are considered to be less critical than runway repairs. It is anticipated that aircraft will taxi slowly and use brakes sparingly. Therefore, repair quality requirements, repair spacing, and braking resistance requirements may be relaxed in order to permit taxiway repairs to be made faster.

2.0 Definition of the following taxiway repair parameters by the aircraft operator will be required to insure that specific aircraft can operate on taxiways that have been repaired at a specific airfield after an attack (Table 5).

2.1 Quality of Repair. The repair quality will be defined in the same manner as Section IV. If possible, only one level of quality will be specified for taxiway repairs.

2.2 Taxiway Repair Spacing. The specified repair quality shall be such that any repair spacing will be acceptable at the approved taxi speeds for a specific aircraft. The aircraft operator will establish and specify aircraft taxi speeds to insure that aircraft loads are compatible with multiple repairs on any spacing on taxiways.

2.3 Taxiway Repaired Width. The minimum acceptable load bearing width for a specific aircraft to taxi on a meandering path between unrepaired craters or nonload bearing surfaces. This path would be swept as best as possible to minimize Foreign Object Damage (FOD).

2.4 Cleared Width. The minimum acceptable width centered on the repaired taxiway from which debris must be removed to the height of the repaired taxiway. This would be required for wing tip, pylon, armament, or propeller obstruction clearance. It is anticipated that only occasional points on the taxiway will be as narrow as the minimum cleared width.

2.5 Swept width. That desirable width which should be swept to prevent debris from being blown and scattered by propeller and jet blast from the taxiing aircraft.

2.6 90° Turn Width. The minimum distance required on a taxiway for an aircraft to make a 90° turn onto an intersecting taxiway or runway. This width should include tolerance to compensate for the pilot's inability to see the actual tire position on the runway.

2.7 180° Turn Width. The minimum width required for a specific aircraft to make a 180° turn, including tolerance to

compensate for the pilots inability to see the actual tire position on the runway.

TABLE 5

F-4E TAXIWAY REPAIR CRITERIA

Taxi Speeds	15 knots (or less)
Repair Quality	"E" or better (Table 2)
Repair Spacing	Greater than 50 feet (21 meters) (any spacing at 5 knots)
Repaired Width Feet (m)	25 (7.6)
Cleared Width Feet (m)	35 (10.7)
Swept Width Feet (m)	35 (10.7)
90° Turn Width Feet (m)	30 (9.1)
180° Turn Width Feet (m)	50 (15.2)

SECTION VIII

FOD CONSIDERATIONS

1.0 One technique under consideration for use in runway repair is crushed stone with or without a FOD cover. Debris from an uncovered repair or from attack damage could potentially cause FOD to aircraft operating on the airfield. Some aircraft are very susceptible to FOD while others are more tolerant, and some aircraft are certified to operate on gravel runways and should be able to operate successfully on crushed stone repair without a FOD cover. The removal of all potential FOD and use of FOD covers on repairs could substantially increase repair time.

2.0 The aircraft operator will provide as much guidance as possible on the ability of a specific aircraft to tolerate debri on the pavement. It must be recognized that evaluation of FOD tolerance of an aircraft involves estimates of acceptable operational risk and that debri removal from a damaged airfield will, of necessity, be incomplete.

SECTION IX

EVACUATION CONSIDERATIONS

1.0 One possible scenario is that the airbase is damaged to the extent where base closure and evacuation is a necessity. Certain things can be done to most aircraft to improve and speed up evacuation procedures. The MOS repair requirements will be those for an Evacuation Strip (ES).

2.0 The following action can be taken to decrease F-4 MOS length and load bearing requirements of a F-4 MOS.

2.1 Reduce Gross Weight. The aircraft operator can reduce gross weight to shorten the takeoff distance required.

2.2 Reduce Tire Pressure. Aircraft tires are designed to operate at a specific percent deflection under static load. When the gross weight is reduced, the tire pressure can also be reduced, thus reducing the aircraft's flotation requirements and consequently, the load bearing requirements for a repair.

2.3 Evacuation Strip Size and Strength. Using the reduced weight and reduced tire pressures, the Evacuation Strip and load bearing requirements should be specified. This may give the airfield manager the option of using a perimeter road, sod surface, or other surface. An example for the F-4E is included as Table 6.

3.0 Special Servicing or Operating Techniques. The aircraft operator should specify any other action that can improve an aircraft's surface roughness capability. For evacuation these special servicing procedures and/or operational techniques should be identified and the subsequent Evacuation Strip runway repair requirements specified. Appendix C contains a sample F-4E evacuation procedure using special non standard servicing of the main gear struts that results in increased roughness tolerance, (High Pressure Struts).

TABLE 6

F-4E EVACUATION STRIP DATA

Gross Weight lbs	44,563 lbs
Center of Gravity	31.1%
Main Gear Tire Pressure, PSI	200
Nose Gear Tire Pressure, PSI	120
Evacuation Strip Length, feet (m)	
1.1 Density Ratio	1,600 (488)
1.0 Density Ratio	2,000 (607)
0.9 Density Ratio	2,400 (732)

NOTES:

1. Full Internal Fuel
2. No External Stores (639 rounds of 20 mm)
3. Repair Load Bearing Capability in accordance with reduced Gross Weight and Main Tire Pressure
4. Roughness Specification should be the same as a standard MOS (section IV or V) except that the Evacuation Strip length may be much shorter.

SECTION X

CONCLUSIONS AND RECOMMENDATIONS

1.0 Conclusions. The data, data formats and responsibilities defined in this report can be used to exchange data between nations for the purpose of defining requirements for rapid repair of bomb damaged runways after an enemy attack. The exchange of this data is essential for NATO interoperability.

2.0 Recommendations. This report is only a first attempt to quantify and document these parameters that establish Rapid Runway Repair specifications. Other individuals or nations may have better techniques for presenting, documenting and measuring the essential parameters. NATO nations should be encouraged to review this report and comment upon its usefulness.

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8. Hag, Delynn R., Aircraft Characteristics For Airfield Pavement Design and Evaluation, AFWL-TR-69-54, Air Force Weapons Laboratory, Kirtland AFB, NM, October 1969. (Unclassified).

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APPENDIX A

PROPOSED F-4E SPECIFICATIONS FOR REPAIR OF BOMB DAMAGED RUNWAYS

TABLE A-1

F-4E MOS REQUIREMENTS

Length	5000 ft (1524 meters)
Width	50 ft (15.24 meters)
Take-off to clear 50 ft obstacle	5700 ft (1767 meters) (3) (4) (6)
MOS Marking	Centerline and Threshold (1)
Abort Requirements	NONE
MOS Marking	Centerline and Threshold (1) (7)
Lighting	MOS edge, Threshold (1)
MOS Direction	(1)
Instrument Approaches	(1)
Barriers/Arrestors	(1) (2)

Notes: (1) Airfield manager will advise aircraft operators of specific details as soon as possible after repairs are complete.

(2) Desired but not required

(3) Worst case density ratio of .9

(4) Dry runway

(5) 38,000 lb Aircraft

(6) Reference 1

(7) Reference 9

TABLE A-2

F-4E REPAIR QUALITY CATEGORIES

	A	B	C	D	E
Maximum Upheaval, inches (cm)	1.5 (4)	3.0 (6)	3.0 (6)	3.0 (8)	4.5 (11)
Sag (See Table A-3)					
Maximum Length of Crater, feet (meter)	N/A	N/A	70 (20)	70 (20)	N/A
Maximum Change in Slope (percent)	3.0	3.0	3.0	3.0	3.0
Special Requirements	(1)	(2)	(2)(3)	(1)(3)	(1)

Special Requirements

(1) Any spacing except that if repairs are closer than 100 feet "D" and "E" repairs must be upgraded, "D" to "A" and "E" to "C" repairs.

(2) Must meet spacing criteria, or upgrade to "A" category.

(3) Maximum length of a single "C" or "D" repair is 70 feet. If a single repair exceeds 70 feet, upgrade to a "B" repair.

(4) For landing aircraft E repairs must be 750 feet apart or upgrade to "D."

TABLE A-3

F-4E REPAIR SAG CRITERIA

	REPAIR CATEGORY				
	A	B	C	D	E
Peak Sag Inches (cm)	1.0 (2.5)	1.0 (2.5)	2.5 (6.5)	2.5 (6.5)	4.0 (10.0)
Nominal Allowable Sag, Inches (cm)	0.5 (1.5)	0.5 (1.5)	2.0 (5.0)	2.0 (5.0)	3.5 (9.0)
Maximum Span of Sag Below Nominal Sag, ft (m)	5 (1.5)	5 (1.5)	10 (3.0)	10 (3.0)	20 (6.0)

TABLE A-4

F-4E UNREPAIRED SCABS

Maximum Depth	1.5 inches (3.8 cm)
Maximum Length Parallel to MOS centerline	2 feet (61 cm)
Maximum Slope of Scab Sides	25%
Spacing Parallel to MOS centerline	No more than 2 scabs per 24 feet (7.3 meters)

TABLE A-5

F-4E TAXIWAY REPAIR CRITERIA

Taxi Speeds	15 knots
Repair Quality	"E" or better (see Table A-3)
Repair Spacing	Greater than 50 feet (any spacing at 5 knots)
Repaired Width Feet (m)	25 (7.6)
Cleared Width Feet (m)	35 (10.7)
Swept Width Feet (m)	35 (10.7)
90° Turn Width Feet (m)	30 (9.1)
180° Turn Width Feet (m)	50 (15.2)

TABLE A-6

F-4E MOS REPAIR QUALITY

UNIDIRECTIONAL MOS

Zone for Quality Feet	Density Ratio .9	1.0	1.1
B	0-1585	0-1250	0-1050
C	1585-2355	1250-1790	1050-1565
D	2355-2855	1790-2290	1565-2065
E	2855-5000	2290-5000	2065-5000

BIDIRECTIONAL MOS

Zone for Quality Feet	Density Ratio .9	1.0	1.1
B	0-1585 3415-5000	0-1250 3750-5000	0-1050
C	1585-2355 2645-3415	1250-1790 3210-3750	1050-1565 3435-5000
D	2355-2645	1790-2290 2710-3210	1565-2065 2935-3435
E	NONE	2290-2710	2065-2935

TABLE A-7

F-4E EVACUATION STRIP DATA*

Gross Weight lbs	44,563
Center of Gravity	31.1%
Main Gear Tire Pressure, psi	200
Nose Gear Tire Pressure, psi	120
Evacuation Strip Length, feet (m)	
1.1 Density Ratio	1,600 (488)
1.0 Density Ratio	2,000 (607)
0.9 Density Ratio	2,400 (732)

*NOTES:

1. Full Internal Fuel
2. No External Stores (639 pounds of 20 mm)
3. Repair Load Bearing Capability in accordance with reduced Gross Weight and Main Tire Pressure
4. Roughness Specifications should be the same as a standard MOS (section IV and V) except that the Evacuation Strip length may be much shorter.

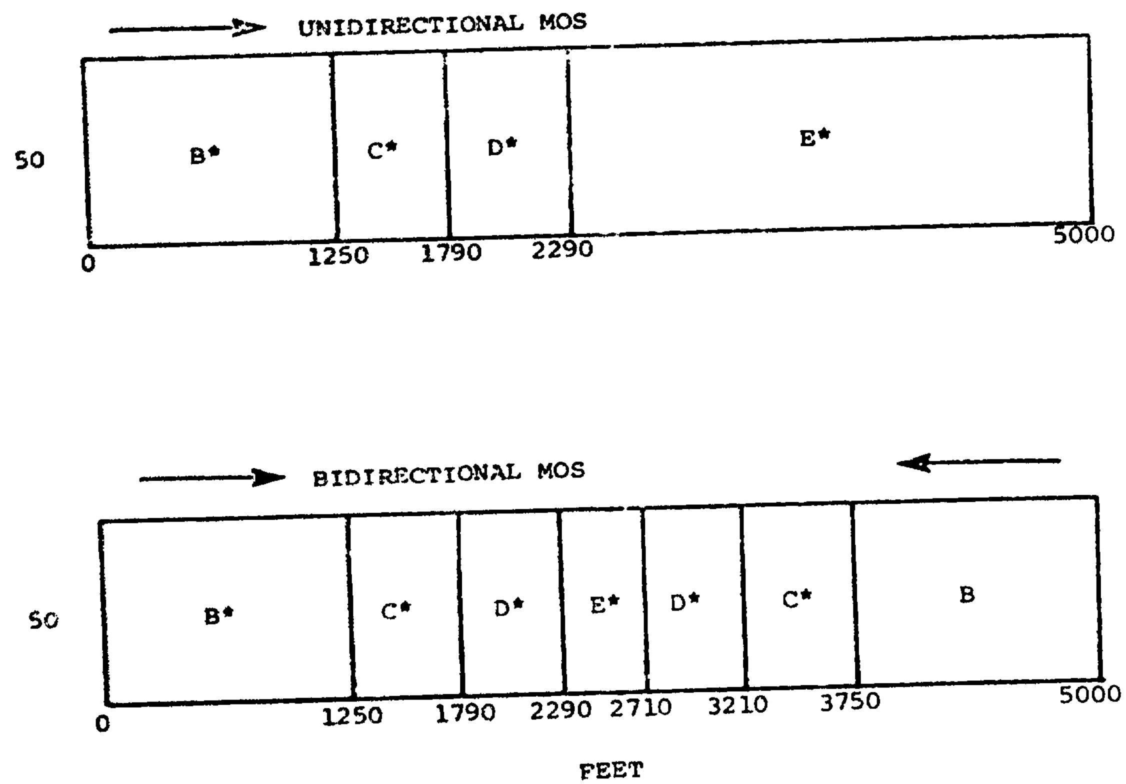


Figure A-1. F-4E MOS Repair Quality vs Locations

NOTES:
1. * or better
2. Density Ratio=1.0
3. Repair Quality is defined in Section V

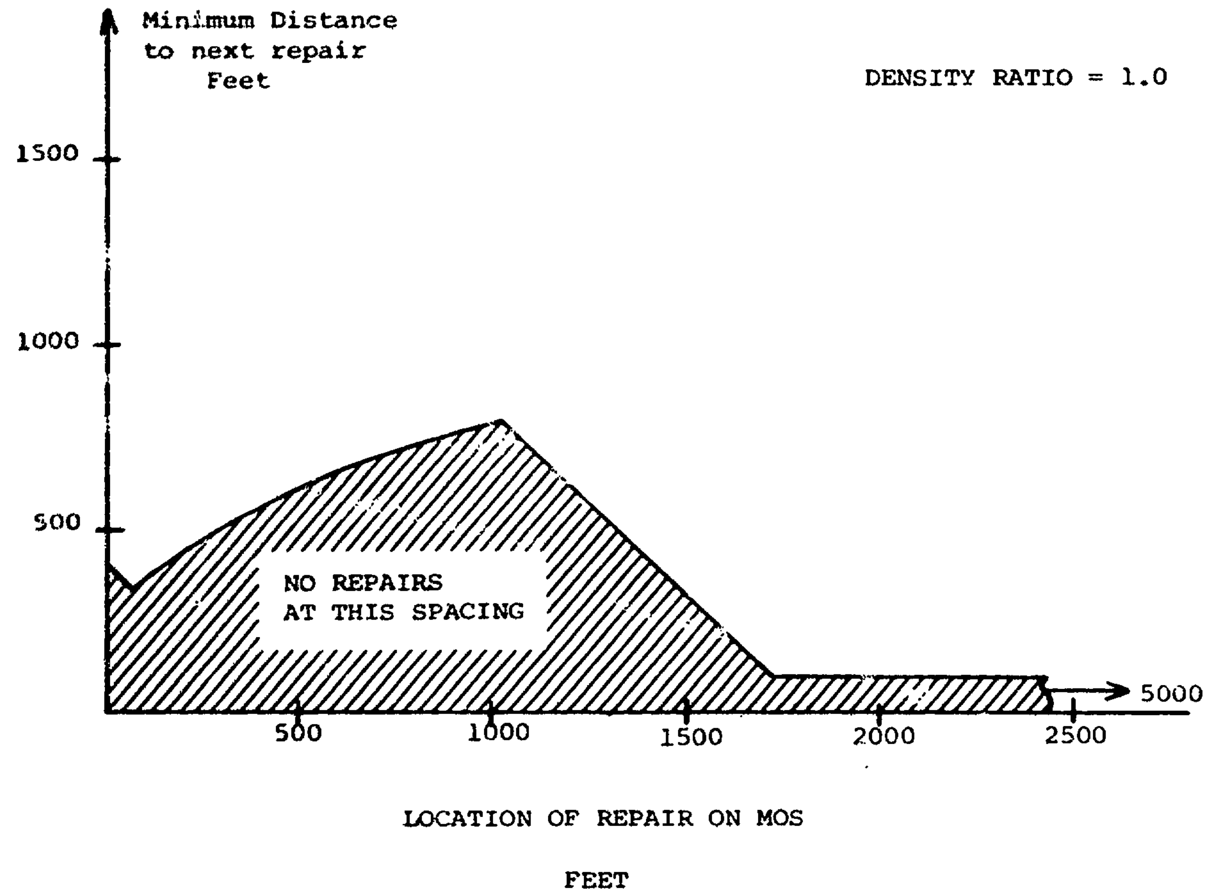
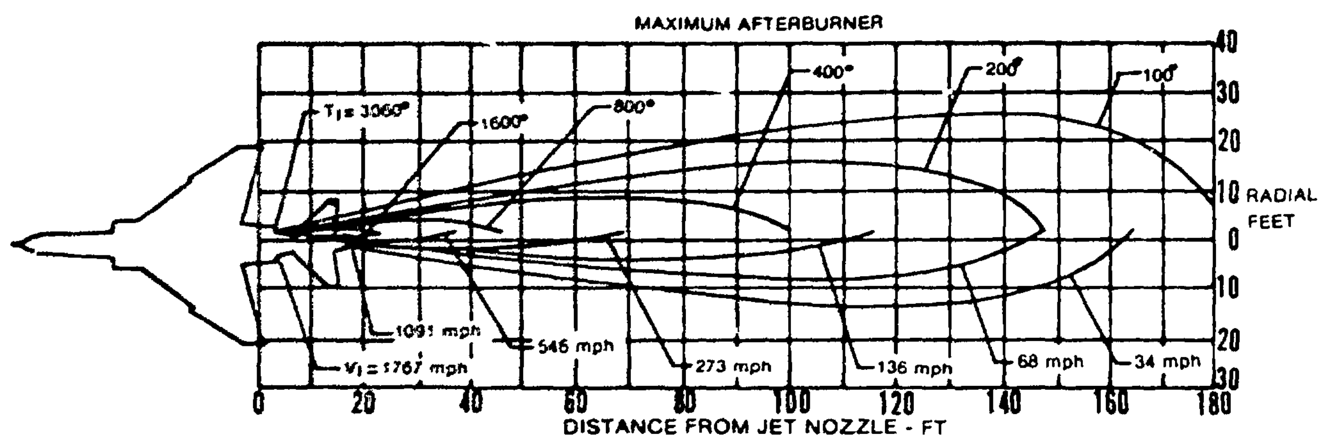


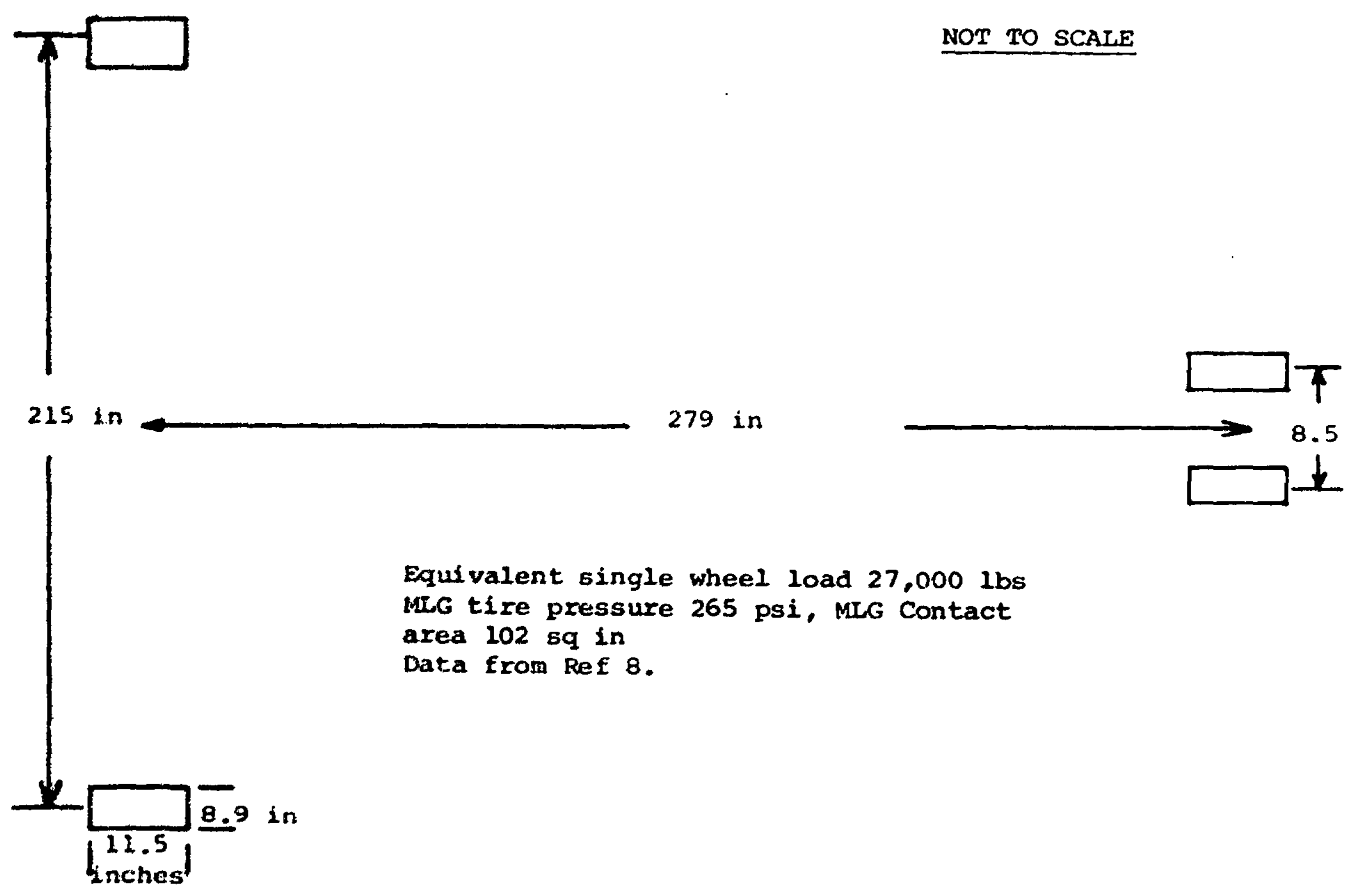
Figure A-2. F-4E MOS Spacing



LEGEND	NOTES
— TEMPERATURE T_j TEMPERATURE AT NOZZLE EXIT - - - DISPERSION LIMIT TEMPERATURE/16 — VELOCITY - MPH V_j VELOCITY AT NOZZLE EXIT - - - DISPERSION LIMIT VELOCITY	1. ALL RATINGS GIVEN ARE FOR A STATIC AIRCRAFT AT SEAL LEVEL ON A STANDARD DAY. 2. FOR CLARITY, ONLY ONE ENGINE JET WAKE IS SHOWN. 3. EXTRACTED FROM TO IF-4E-I

Figure A-3. F-4E Thrust Effects

NOT TO SCALE



Equivalent single wheel load 27,000 lbs
MLG tire pressure 265 psi, MLG Contact
area 102 sq in
Data from Ref 8.

Figure A-4. F-4E Wheel Pattern

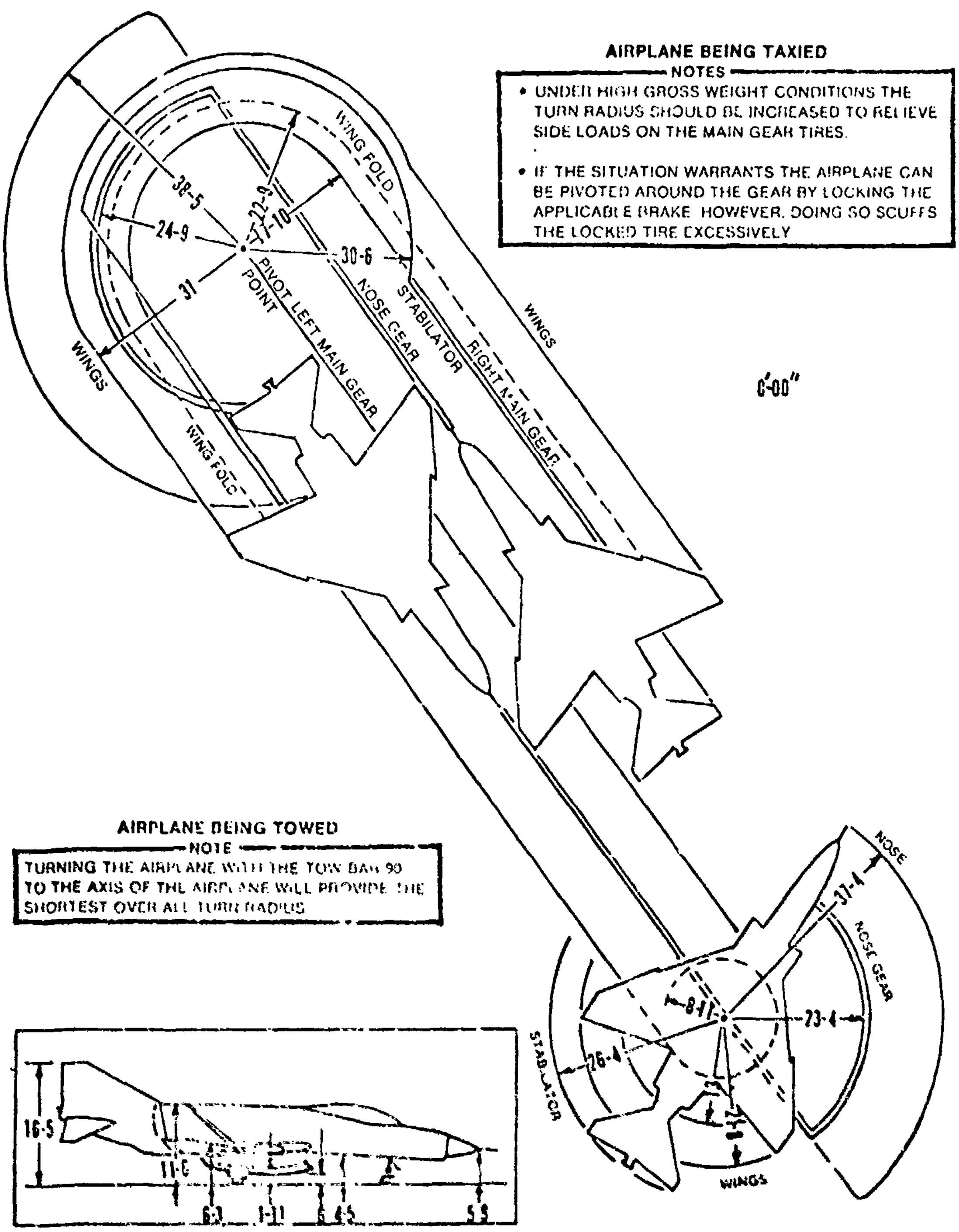


Figure A-5. F-4E Turning Radius and Ground Clearance

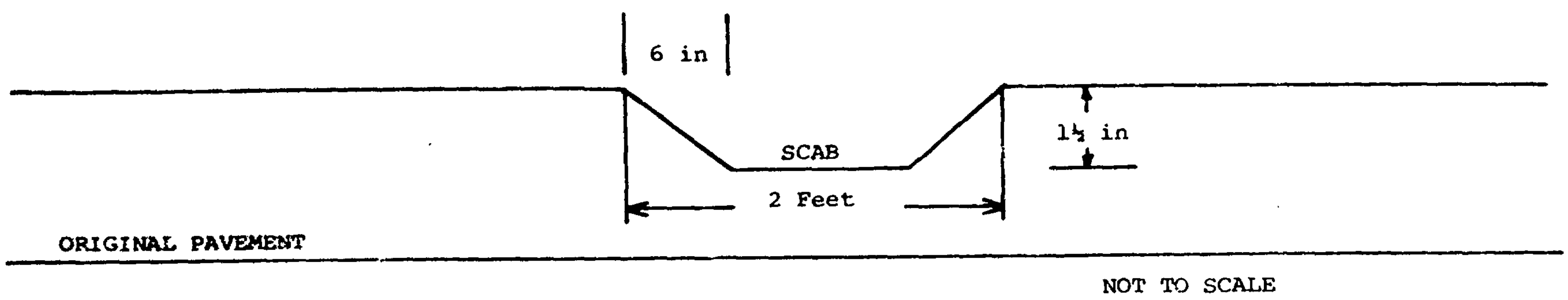


Figure A-6. F-4E Unrepaired Scabs

APPENDIX B

GLOSSARY

GLOSSARY

Craters/Pavement Damage Categories.

Camouflet. Pavement damage caused by a deep penetrator which creates a void in the base course or subbase and an uplift of the pavement. Collapse or partial collapse of the void is likely. Camouflets are considered to be a form of small craters.

Large Crater. Large craters are pavement damage from conventional weapons that penetrates the subgrade and has an apparant crater diameter greater than 15 feet (Figure B-1).

Small Crater. Small craters are pavement damage from conventional weapons that penetrate/disturb the subgrade, and result in possible pavement upheaval around the crater edge, and an apparent crater diameter of less than 15 feet.

Scab. Pavement damage that does not penetrate the pavement base course and which results in a damage area that could typically be up to 5 feet (1.5 m) in diameter (Figure B-2).

Damage Length. The length, parallel to the MOS centerline, including upheaved pavement, of the damaged pavement. If the repair has an FOD cover or a mat with a significant thickness then the damage length includes the cover or mat (Reference Figure B-2). The measurement includes all material including upheaved pavement, repair mats, etc., that may not be at the original pavement level and would result in surface roughness.

Debris. Material ejected from the crater including broken pavement and soil. Debris is sometimes useable as backfill material particularly for large crater repair but for very small crater repair it may not be adviseable.

Diameters.

Apparent Crater Diameter. The apparent crater diameter is the visible diameter of the crater, inside edge to inside edge at the original surface level, before debris is removed. In actual practice this can be measured from pavement edge to pavement edge. (Reference Figure B-3)

Actual Damage Diameter. The damage diameter is the diameter across the upheaved pavement from the start of upheaval on one side of the crater to the end of upheaval on the far side of the crater. (Reference Figure B-3)

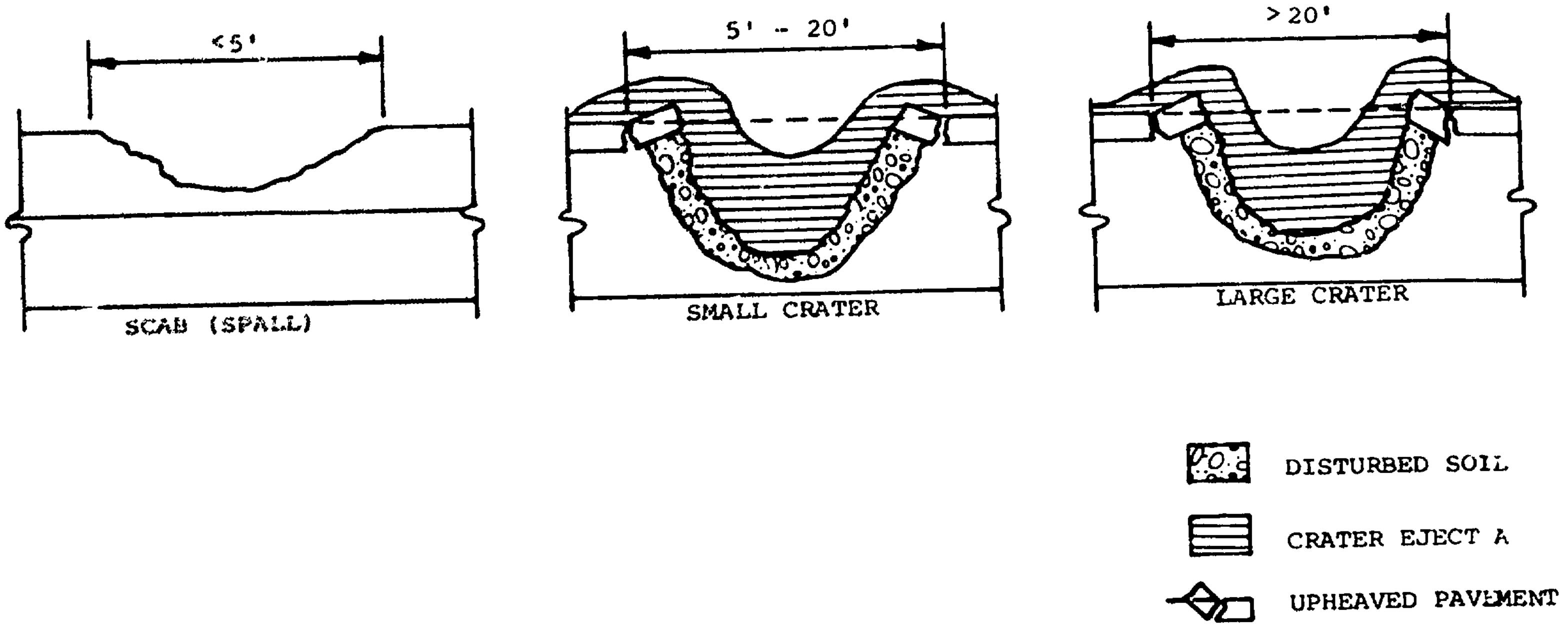


Figure B-1. Pavement Damage Categories

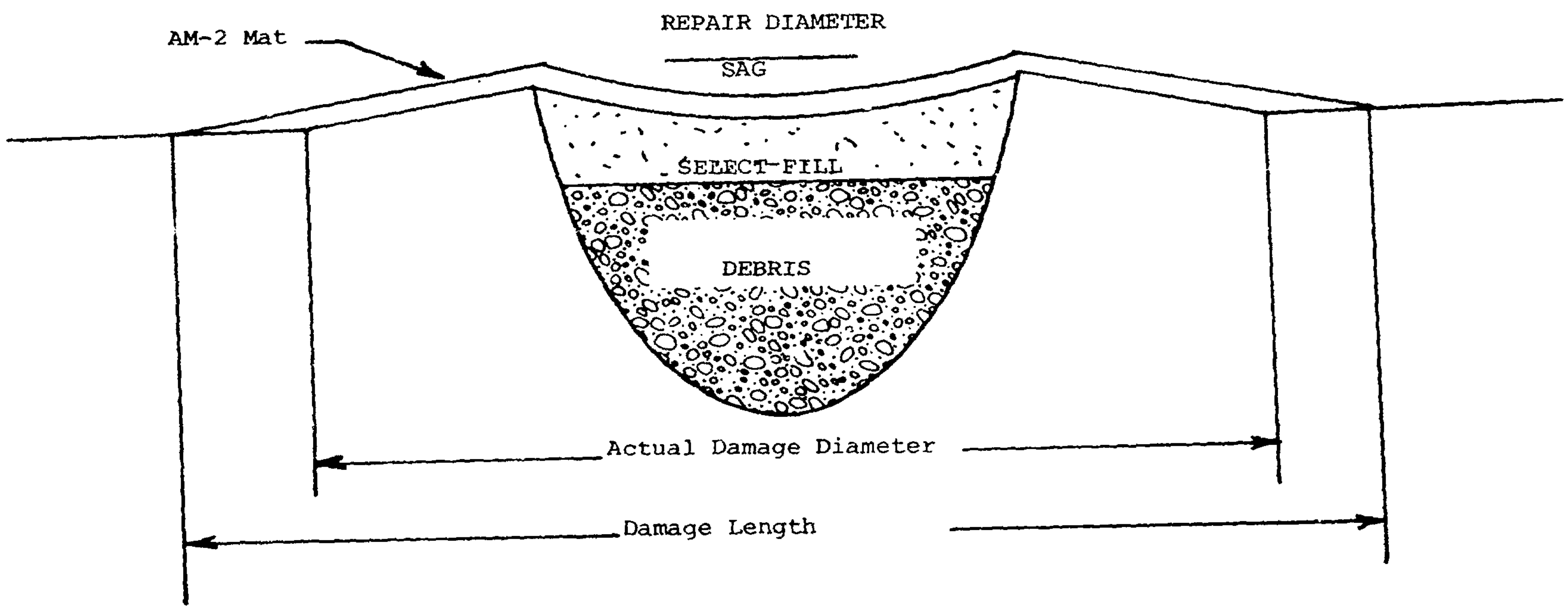


Figure B-2. Repair Using AM-2 Mat

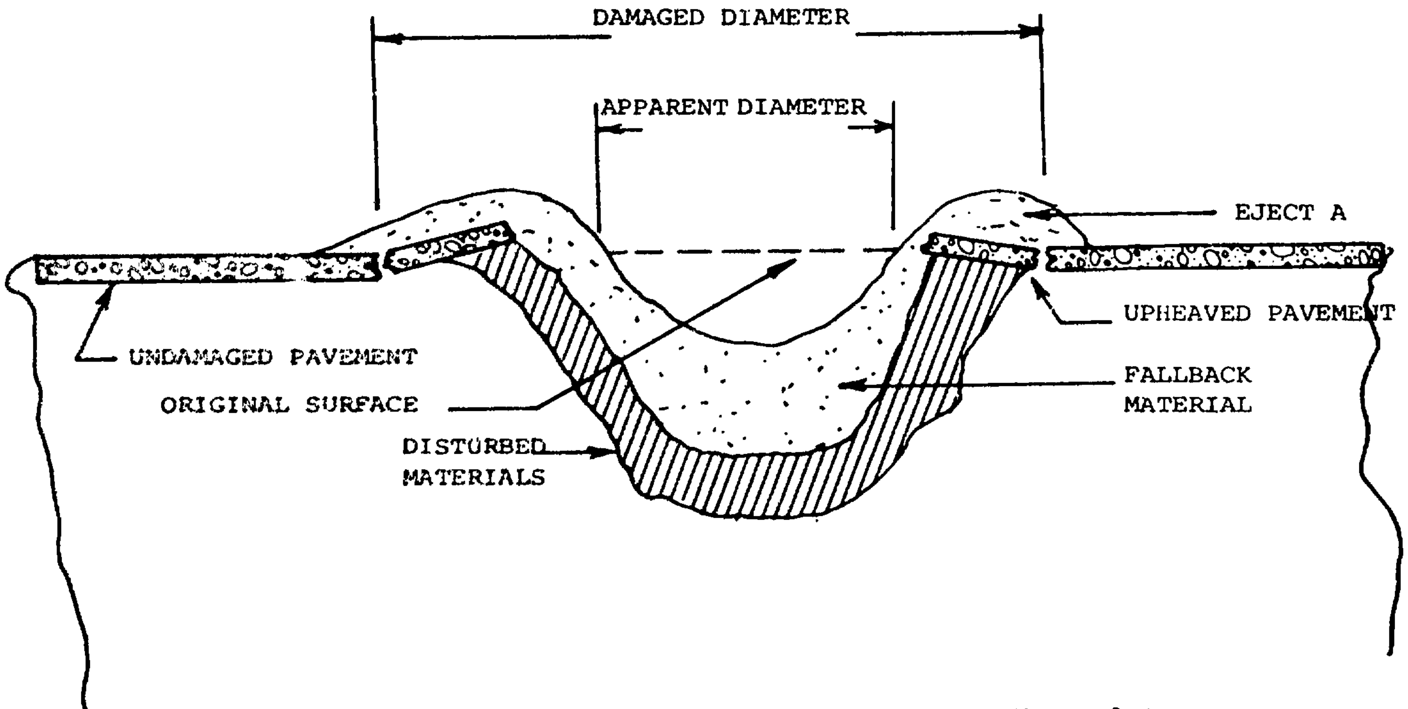


Figure B-3. Apparent Crater Nomenclature

Repair Diameter. The repair diameter is the maximum distance across the repair, not necessarily parallel to the MOS centerline. The repair diameter is measured from the unremoved pavement on one side of the repair to the unremoved pavement on the other side and represents the portion of the repair that has a significantly different load bearing capability than the original pavement (Figure B-2).

Evacuation Strip (ES). The minimum size and reduced load bearing capability operating strip required to launch but not recover a specific aircraft under restricted conditions such as reduced gross weights and reduced tire pressure.

Fallback. Crater material which is ejected at such a high angle that it falls back into the crater.

Foreign Object Damage (FOD). Damage to aircraft can be caused by small loose objects such as debris on the runway--being ingested in the engine, damaging the tires, or being thrust into other parts of the aircraft.

Minimum Operating Strip (MOS). The minimum operating strip is the smallest amount of area that an airfield manager must repair to launch and recover aircraft after an attack. Selection of this MOS will depend upon mission requirements, taxi access, resources available and estimated time to repair. The current NATO standard for an MOS is 50 feet wide by 5000 feet long.

Repair Quality. The repair quality is identified by a series of progressively less restrictive specifications identified as A, B, C, D, etc., such that a higher quality level is always better than a lower quality level and can be used in place of the lower quality level. For example, a B level meets or exceeds the C level specification and can be used in place of a C repair, but does not meet or exceed the A level repair requirements.

Sag. Sag is the vertical distance between the low points of a repair and an imaginary repair surface. In order to measure sag, the imaginary repair surface must be established by stretching a string across the repair so that it contacts the pavement just outside the start of the upheaval as shown in Figure B-4. Then the vertical distance from the repair surface to the string must be measured. Sag will probably increase with aircraft traffic as the fill settles.

Peak Sag. The peak distance below the string is the peak sag. This peak sag must be associated with a "maximum span below nominal sag" as discussed below.

Nominal Sag. This sag is the maximum allowable sag that is acceptable without consideration for sag length. There is no associated sag span with the nominal sag.

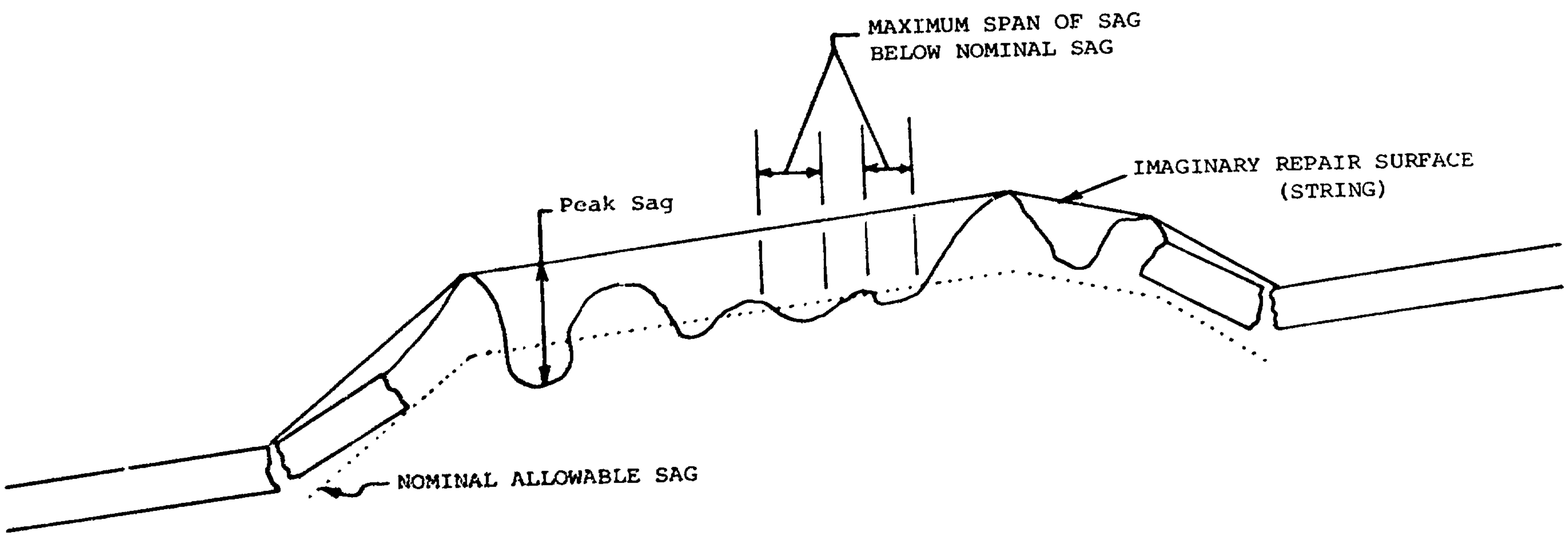


Figure B-4 Sag Measurement

Maximum Span below Nominal Sag. This parameter defines how wide (how long down the MOS) that sag can exceed the nominal sag towards the peak sag limit. The repair surface must return to a point above the nominal sag at least once in each maximum span. This parameter allows sag to approach the peak allowable sag as long as the effective frequency does not stimulate reinforcement of aircraft dynamic loads.

Upheaval.

Pavement Upheaval. The vertical displacement of the airfield pavement around the edge of an explosion produced crater. (See Figure B-3.) The pavement upheaval is within the crater damage diameter, but is outside the apparent crater diameter. The upheaved pavement may be completely removed, partly removed or not removed during the repair process depending upon the repair quality level.

Peak Upheaval. The peak upheaval is the repair peak highest above a line between the undamaged pavement on each side of the repair. The measurement of the upheaval in the field is performed using upheaval markers as shown in Figure B-4. These markers permit a string to be stretched taut at certain heights above the pavement surfaces. The upheaval marker posts should be located on opposite sides of each crater, outside the limits of pavement upheaval. A string should be stretched between the posts at equal heights above the pavement, corresponding to the allowable maximum repair upheaval for the applicable repair category. The entire crater repair must lie beneath the string to meet the maximum upheaval criteria. One of the current repair techniques uses an aluminum mat on top of select fill in the crater. The peak upheaval, includes the thickness of this repair mat.

Repair Upheaval. Repair upheaval is the height of the repair above the original pavement elevation. It occurs where the pavement has been raised by the explosion around the edge of the crater or by overfill in the crater during the repair operation. Repair upheaval includes the height of an FOD cover or a repair mat such as the US AM-2 mat or the UK Class 60 mat if it is used for a particular repair. (Reference Figure B-5)

Percent Change in Slope. This parameter establishes the maximum rate of change of the repair height relative to the original pavement surface, and is applicable to both the upheaved pavement and the repair surface. For example, if the damaged pavement is heaved up 1.5 inches in 5 feet, then this represents a [1.5/5x12) = 0.025] 2.5 percent change in slope from the adjacent undamaged pavement. Typically, change in slope would be measured with a template.

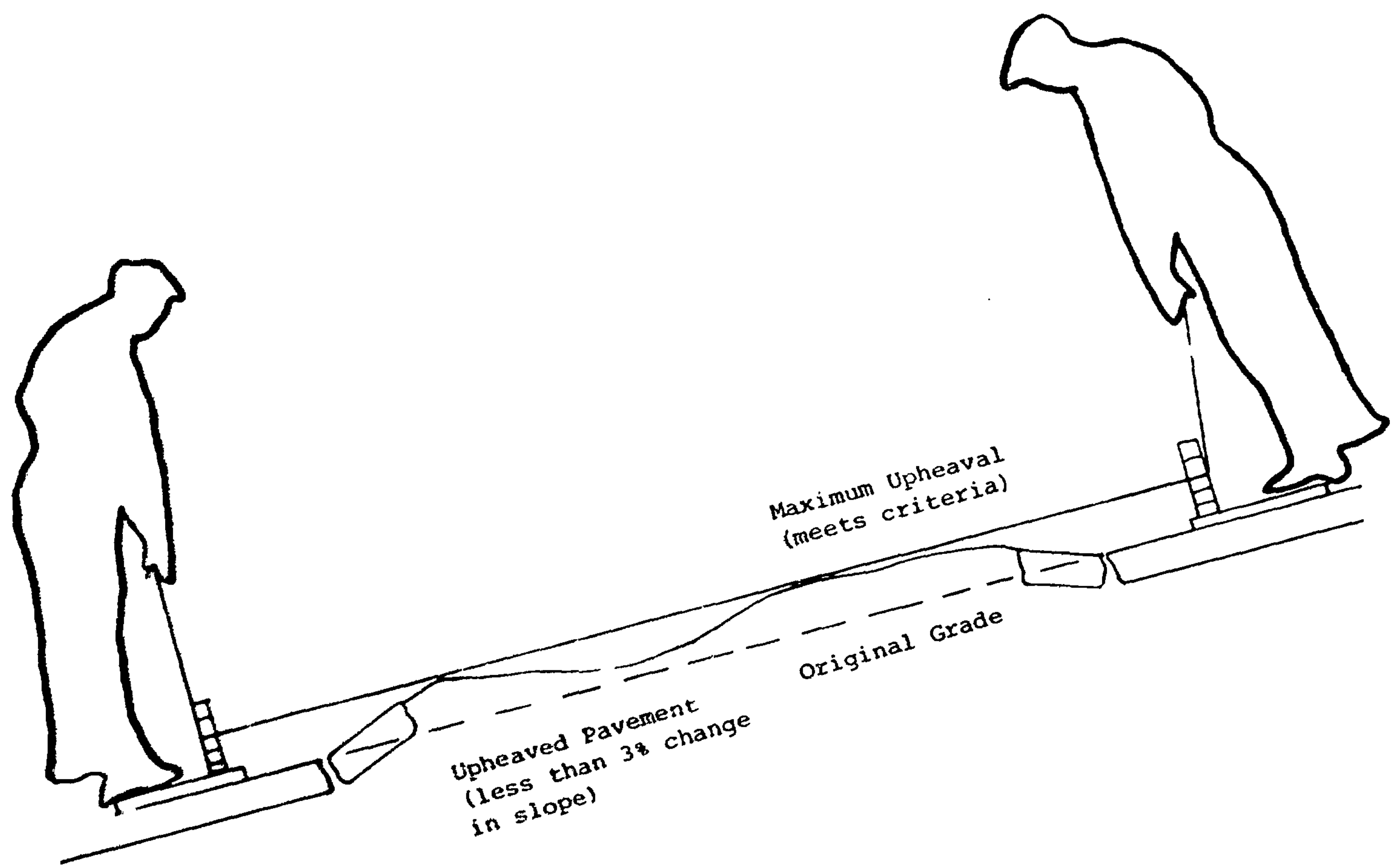


Figure B-5. Peak Upheavel Measurement

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APPENDIX C

PROPOSED SPECIAL SERVICING PROCEDURES FOR F-4E EVACUATIONS

PROPOSED SPECIAL SERVICING PROCEDURES

FOR F-4E EVACUATIONS (HIGH PRESSURE STRUT)

1.0 If the airfield is damaged to the extent that evacuation is required and it is necessary to make extremely rough repairs special servicing of the F-4E main gear struts can significantly increase the ability of the F-4E to tolerate roughness.

2.0 The aircraft gross weight and tire pressure should be reduced as discussed in Section IX of this report. These changes will decrease the Evacuation Strip length and load bearing requirements as shown in Table C-1.

3.0 The main landing gear upper chamber strut pressure should be increased as outlined in Table C-2. This will increase the roughness capability of the F-4E to allow "D" quality repairs with no spacing restriction. "E" quality repair may be performed after the first 1000 feet without spacing restriction.

4.0 In this configuration the F-4E must fly with the main landing gear lock pin installed and therefore with the main landing gear down. This results in a substantially reduced range.

TABLE C-1

F-4E EVACUATION STRIP FOR VERY ROUGH SURFACE

USING HIGH PRESSURE STRUT*

Gross Weight lbs	44,563
Center of Gravity	31.1%
Range NM	650
Main Gear Tire Pressure, PSI	200
Nose Gear Tire Pressure, PSI	120
Main Gear Upper Chamber Strut Pressure	See Table C-2
Evacuation Strip Length, feet (m)	
1.1 Density Ratio	2,400 (732)
1.0 Density Ratio	2,000 (607)
0.9 Density Ratio	1,600 (488)
Repair Quality (any spacing)	
Any location	"D"
After first 1,000 ft (304 m)	"E"

*NOTES:

1. Full Internal Fuel
2. No External Stores (639 pounds of 20 mm)
3. Load bearing capability in accordance with reduced tire pressure and gross weight
4. Main Gear must be Extended. Use drag index of 30 for main gear down range. Gear down airspeed limit is 250 knots calibrated airspeed.

TABLE C-2

EMERGENCY SERVICING OF MAIN LANDING GEAR STRUTS

P/N 53-41400, 7027676-10, -20, -50, -60, -90, and -100

WARNING

THIS SERVICING PROCEDURE IS TO BE USED ONLY WHEN TAXI STRIP AND RUNWAY SURFACE HAVE BEEN DAMAGED AND THE SURFACE ROUGHNESS PREVENTS NORMAL TAKE OFF. THIS PROCEDURE WILL BE USED ONLY WHEN IT IS ESSENTIAL FOR EVACUATION OF AIRCRAFT TO PREVENT LOSS OF AIRCRAFT.

1. Insure lower chamber of MLG strut is serviced in accordance with T.O. IF-4 (E)-2-2.

WARNING

SAFETY GLASSES OR FACE SHIELD WILL BE WORN WHEN SERVICING WITH NITROGEN OR WITH MEDIUM OR HIGH PRESSURE AIR.

NITROGEN IS PREFERRED FOR STRUT SERVICING, BUT CLEAN, DRY AIR MAY BE USED IF NITROGEN IS NOT AVAILABLE. NEVER USE OXYGEN OR HYDROGEN TO SERVICE STRUT OR EXPLOSION MAY RESULT WITH INJURY OR DEATH TO PERSONNEL.

BEFORE REMOVING VALVE CAP, INSURE THAT SWIVEL HEX NUT IS TIGHT. REMOVE VALVE CAP SLOWLY TO PREVENT SUDDEN RELEASE OF HIGH PNEUMATIC PRESSURE.

2. Tighten swivel hex nut (4), then remove valve cap (10) from upper air charge valve (3).

WARNING

Do NOT STAND DIRECTLY IN FRONT OF AIR CHARGE VALVE (3) WHILE BLEEDING PRESSURE FROM UPPER CHAMBER OR INJURY TO PERSONNEL MAY RESULT.

CAUTION

RATE OF DISCHARGE IS ESTABLISHED BY AMOUNT SWIVEL NUT IS LOOSENED. VALVE MAY BE DAMAGED IF NUT IS LOOSENED MORE THAN TWO TURNS.

3. Slowly discharge air or nitrogen from upper chamber by loosening swivel nut (4) a maximum of two turns (turn clockwise). Rock aircraft to overcome friction.

TABLE C-2 CONTINUED

EMERGENCY SERVICING OF MAIN LANDING GEAR STRUTS

P/N 53-41400, 7027676-10, -20, -50, -60, -90, and -100

4. Disconnect strut gage (2) and replace with plug, P/N AN814-4L and "O" ring P/N MS28778-4, prior to servicing to the higher pressure. Retain strut gage for reinstallation when pressure is changed to normal pressure. Safety wire plug to adjacent air charge valve.

5. Attach hydraulic hand pump to upper chamber air charge valve (3) and pump 8 to 16 fluid ounces (1/2 to 1 pint) of hydraulic fluid into upper chamber. Loosen hose connection at intervals to allow trapped air to escape.

6. Continue filling upper chamber until a minimum of 8 fluid ounces (free of air bubbles) flows out air charge valve (3) when filler hose is removed.

7. Connect gage assembly (5) with 0 to 4000 PSI gage to upper chamber air charge valve (3). Connect nitrogen or air pressure source to gage assembly.

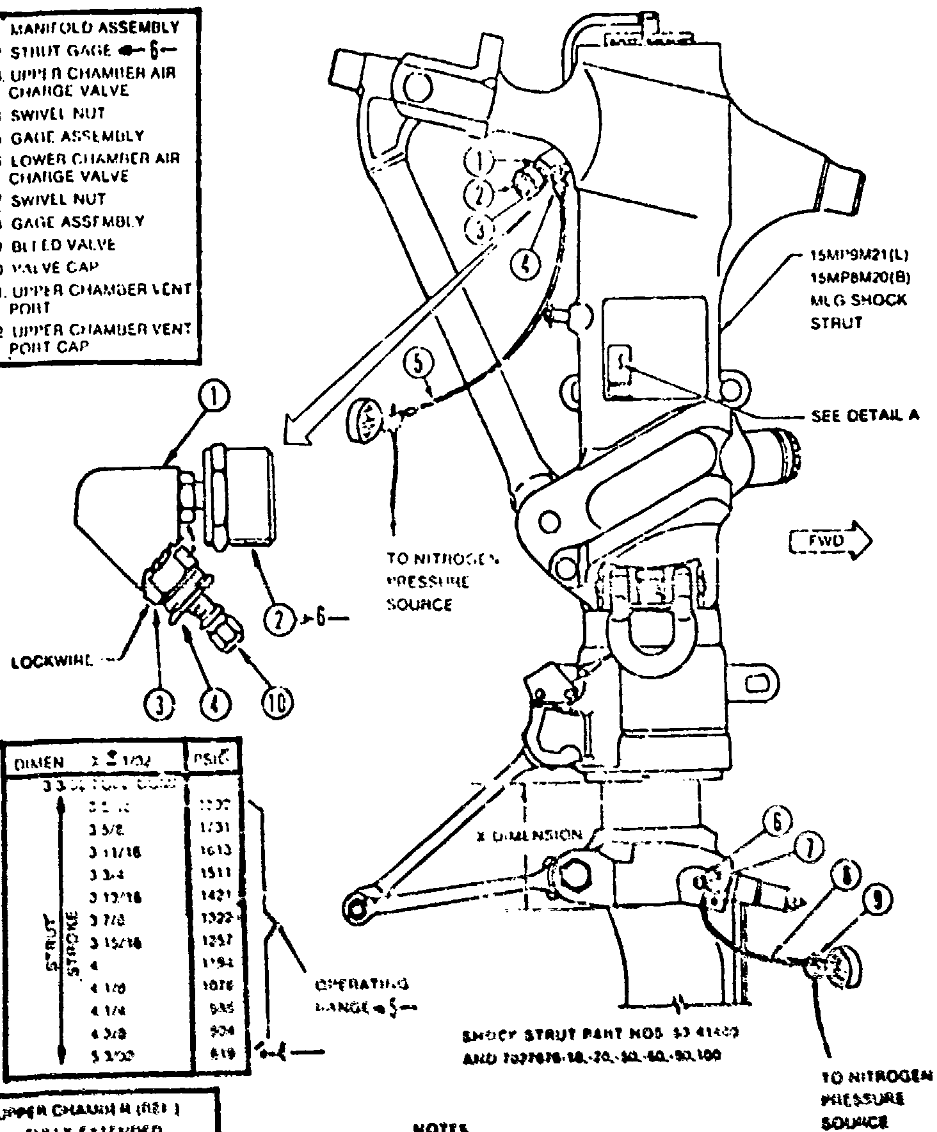
8. Inflate upper chamber until the X dimension of Figure 1 is increased by 2.5 inches +0 -.5. Rock aircraft to overcome friction. Do not exceed maximum nitrogen or air pressure of 1,800 pounds PSI when servicing upper chamber with higher pressure.

9. Torque swivel nut (4) to 50-70 inch-pounds. Check air charge valve (3) for leaks. Remove gage assembly (5) and replace valve cap (10) and tighten fingertight.

WARNING

MAIN GEAR CANNOT BE RETRACTED WITH HIGHER PRESSURE IN CHAMBER OR SHRINK-LINK FAILURE WILL OCCUR. INSTALL MLG ACTUATOR SAFETY STRUTS AND MLG INBOARD DOOR PIN. RETRACTION OF NOSE LANDING GEAR IS OPTION'L.

10. The upper chamber pressure will be serviced to the normal pressure in accordance with T.O. 1F4(E)-2-2. Remove MLG actuator safety struts and MLG inboard door pins when aircraft has been evacuated to an undamaged airfield. Visual inspection will be made in MLG wheel wells to insure no damage has occurred.



DIMEN X ± 1/32	PSIG
3 3[illegible] FULL COMP	
[illegible]	[illegible]
3 5/8	1731
3 11/16	1613
3 3/4	1511
3 13/16	1421
3 7/8	1322
3 15/16	1257
4	1194
4 1/8	1076
4 1/4	985
4 3/8	904
5 3/32	619

STRUT STROKE

UPPER CHAMBER (REF.) FULLY EXTENDED	
DIMEN S	PSIG
18 31/32	15 ± 2

NOTES

1 STRUT SHOWN REMOVED FOR CLARITY
2 THIS VIEW TYPICAL FOR BOTH LEFT AND RIGHT MLG SHOCK STRUTS. LEFT STRUT SH[illegible]
3 ALL DIMENSIONS SHOWN ARE IN INCHES UNLESS OTHERWISE SPECIFIED
4 HIGH PRESSURE [illegible] ON FULLY EXTENDED
5 EXTENSIONS NOT WITHIN THE OPERATING RANGE UNDER OPERATIONAL CIRCUMSTANCES REQUIRES STRUT RESERVICING
6 53 [illegible] AND 7027676-18,-20,[illegible] SERIES STRUTS REQUIRE GAGE [illegible] 53 [illegible] AND [illegible] STRUTS REQUIRE GAGE [illegible] GAGE MAY BE USED ON ALL SERIES OF STRUTS